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ABSTRACT

Many current studies have discovered that students tend to use either an Aristotelian or the Medieval impetus model rather than the Newtonian view in order to explain their experience. This preconceived knowledge may be important for students in learning mechanics. The purpose of this study was to identify and confirm the existence of a non-Newtonian view of certain mechanical concepts among fourth-grade and eleventh-grade students and to test the relationships between preconceived knowledge and giftedness. The gifted students were classified by their IQ scores (130 or above). Results showed that the findings were generally consistent with other studies indicating that students use more of an Aristotelian-Impetus model than a Newtonian view. There was no difference between gifted and non-gifted samples either at the fourth or eleventh grade in the preconceived knowledge test. This result suggests that students from samples of diverse intellectual development possess similar preconceived views about motion. Appendices include a Piagetian Formal Reasoning Test, Preconceived Knowledge Test, bibliography and an index. (YP)

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A STUDY OF PRECONCEIVED KNOWLEDGE OF MECHANICAL CONCEPTS AMONG ELEMENTARY AND SECONDARY GIFTED LEARNERS

PLACEK, W. 1985

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University of Pennsylvania Ph.D. 1985

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A STUDY OF PRECONCEIVED KNOWLEDGE OF MECHANICAL CONCEPTS AMONG ELEMENTARY AND SECONDARY GIFTED LEARNERS

WALTER A. PLACEK, JR.

A DISSERTATION

in

Education

Presented to the Faculties of the University of Pennsylvania in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy.

1985

Ryda D. Rose
Supervisor of Dissertation

Dell H Hymes
Graduate Group Chairperson

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This is dedicated to my wife
BARBARA
for caring so much.

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Chapter 1

INTRODUCTION TO THE PROBLEM

During the dawn of the Atomic Age, Erwin Schrodinger, Nobel Laureate in physics, felt that the chief and lofty aim of science should be to enhance the joy of living and the knowledge of nature as its own reward (Schrodinger, 1935). Physics has been long recognized as the fundamental basis for the present structure of scientific knowledge and Newtonian mechanics as the essential keystone of this structure (Butterfield, 1965; Russell, 1945; Whitehead, 1948). In spite of the fundamental nature of Newtonian mechanics, it is apparent the concepts included therein are difficult to understand. According to Kolody (1977), physics teachers and students agree that mechanics is difficult to teach and to learn.

In 1938, Einstein recognized the difficulty in comprehending what appeared to be obvious. In discussing "motion," Einstein said that the explanation of even the most obvious motion, such as pushing a cart or throwing a stone was, in fact, very intricate and by no means obvious. Einstein, and other great scientists, viewed this act of making "sense" of these common experiences as the essence of science (Einstein & Infeld, 1938).

Man has always demonstrated an intense desire to understand the basis for both heavenly and earthly motion. Since the beginning of recorded history, philosophers and scientists have been preoccupied with motion (Butterfield, 1965; Holton, 1973). For the most part, these questions remained mysteries through the Middle Ages. In the 16th century, the evolution of new theories of motion came through observation and the combination of sets of ideas with geometric analysis. Men like Copernicus and Kepler paved the way for Galileo and Newton, who rewrote the physics books for all times. Their ideas on motion were so successful in explaining mechanical phenomena that they remain in use to this day. These principles are known as "Newtonian Mechanics."

Since then man has possessed a model for the comprehension and accurate prediction for all classical motion. Yet current studies dealing with how students think about physics reveal that after 300 years the Galilean and Newtonian solutions to the riddles of motion are still elusive and obscure to most of us (Champagne, Klopfer, & Anderson, 1980; McCloskey, 1983; McDermott, 1984).

Researchers have discovered that students tend to use either an Aristotelian or the Medieval "impetus" model in order to explain their experiences (Champagne, et al., 1980; Clement, 1982; Driver, 1973; Leboutet-Barrell, 1976; Viennot, 1979). These non-Newtonian perceptions, based on an intuitive interpretation of spontaneous observations, provide the student with a reasonable, believable, and persistent model for understanding his/her world. In the past 10 years, the process by which students come to possess and use this preconceived knowledge has given inspiration to a growing body of research, the bulk of which considers the role of preconceived knowledge in the learning of science (McDermott, 1984).

The results of research in preconceived knowledge show that students emerge from their study of science without a functional understanding of certain fundamental concepts (Champagne, Hoz, & Klopfer, 1983). These problems exist at all levels of education with very little difference across diverse age groups and have proved to be highly resistant to instruction (McDermott, 1984). If conceptual understanding is a primary goal of science instruction, then our educational efforts must reflect this emphasis. The purposes of science education have long been a concern of scientists and educators alike. The English philosopher, Francis Bacon (1620), insisted that the real value in knowing science was to "improve man's lot rather than provide pleasures of the mind." When one considers the issues and concerns raised by the various national reports of the last 2 to 3 years, (i.e., Nation at Risk, 1983), Bacon's attitude was prophetic. Thomas Huxley in 1850 stated that science was worth knowing simply because it gratified the intellect and satisfied our curiosity about nature (Thornburg, 1984). Seventy years ago Judd (1915) recognized that students lacked enthusiasm for "textbook science." He said that students "get into the habit of thinking of science as verbal additions to experiences, and they faithfully learn the words and keep them in store against that time when a teacher may demand them" (pp. 334-336). Even Einstein was interested in how we learn about nature. In 1938, he said that our "wondering" about nature occurs when our experiences are in conflit with our engrained perceptions of the physical world. Consequently, he inferred that these conflicts decisively affect the way we interpret our experiences (Einstein & Infeld, 1938). The current research indicates this is still very much the case.

The interest in the role of preconceived knowledge in learning science has given science educators a model for developing an instructional strategy which acknowledges these student-held views. This comes during a period of national concern for the apparent shortcomings of our educational systems, particularly as they relate to science education. Not since the late 1950s and early 1960s, following Russia's launching of Sputnik in 1957, has as much interest been stirred in science education as at the present time. During that period the major emphasis was on teacher training programs and curricular innovations. The current research, however, focuses on the cognitive and intellectual skills required to learn science; thus, the emphasis has switched from "what" we learn to "how" we learn (Renner & Lawson, 1973).

Science education has again come into national focus as a variety of commissions have analyzed the status of student achievement and program viability. The National Commission on Excellence in Education, reporting in 1983, sounded an alarm which goes beyond the intellectual and pedagogical goals of our educational system. The report goes to the very heart of our continued existence as a nation. Education has become an issue of national security (Nation at Risk, 1983). The Commission has recommended that science education provide for the application of scientific knowledge to everyday experiences and that emphasis be placed not on learning facts but on "enthusiasm for learning."

Significance of the Study

John Dewey, the distinguished American philosopher writing on educational issues of the early 20th century, argued that science education serves two necessary purposes. First, Dewey insisted that courses should prepare students to function productively in society and should relate to the student's everyday experiences. Secondly, he felt that science education has great value as an intellectual exercise. He stressed the importance of developing "scientific habits of mind" as an aid to sound thinking in all fields (Dewey, 1916). According to Champagne and Klopfer (1977), Dewey's views regarding scientific thinking persist today among science educators; yet very little has been accomplished in the way of transforming this belief into classroom practice. The reason for transformation failure is that the general public and students alike are not convinced that understanding science is necessary to understanding the world (Arons, 1976; Hurd, 1970). Writing in the October 21, 1983 editorial of the Christian Science Monitor science writer, Craig Savoye, reported that there is a public perception of science as non-important. According to one study cited in Savoye's article, 50% of the students entering junior high school say they like science, but only one half of those students feel that way when they leave junior high school.

Speaking at the Wingspread Conference sponsored by the Association of American Colleges in June, 1982, Saxon a former physics teacher and President of the University of California, discussed the discrepancies between scientific knowledge and the usefulness of that knowledge. He contended that the general population is unable to distinguish between sense and nonsense when it comes to science. The problem is that educated, intelligent, inquisitive people are unable to bring informed judgment consistently to bear on questions connected in almost any way with science and technology. According to Saxon, this contradiction is inevitable. Modern science deals with the physical world at a level so abstract and so remote from everyday experiences that there is no way such experiences could act as a guide in distinguishing sense from nonsense. Science expresses itself in the language of abstraction and has become inaccessible to the general public; yet it is this abstraction that enables science to express the relations in the physical world in terms of such great general laws as those of gravity, relativity, and quantum mechanics (Whitehead, 1968). According to Saxon (1982), this problem is neither new nor original. How we can bridge the knowledge built up by experiences with the conceptual abstract models of the scientist is a persisting question. However, research dealing with the preconceived views held by children concerning mechanical concepts and the ways these views influence the learning process will no doubt help in finding an answer or answers.

Researchers have examined several aspects of the role of preconceived knowledge in the learning of science. Champagne, et al. (1980), Viennot (1979), McCloskey (1983), Lochhead (1979), McDermott (1984) and others have been very active in this area. Many of the studies have examined the relationship between the length of time during which the students studied physics and the qualitative understanding of certain basic concepts in mechanics (Sjoberg & Lie, 1981). One would assume that more intellectually capable students hold fewer misconceptions of physical concepts and consequently demonstrate a more correct view of the physical world. Research, however, indicates the opposite is true. Studies done by Trowbridge and McDermott (1981) and Peters (1982) have shown that even honors physics students on the college and high school levels confuse the fundamental concept of motion when asked to apply it to actual experiences in the laboratory.

According to McDermott (1984), the bulk of the research on preconceived knowledge seems to lean in the direction of comparing physics students with non-physics students. There is no evidence in the literature that comparative levels of preconceived knowledge of mechanical concepts have been examined in the gifted and non-gifted students on either the elementary or secondary levels.

Furthermore, in personal conversations with McCloskey and Champagne by telephone (April, 1984) and McDermott, Lochhead, and Elyon at the American Association of Physics Teachers' meeting, University of Maryland (June 25-26, 1984), it was indicated to this researcher that studies on preconceived knowledge in mechanics among the gifted vs. non-gifted students is virtually non-existent at any academic level. One purpose of this study is to extend our knowledge in this area by examining the relationship between preconceived knowledge and giftedness at levels of schooling where no study has yet been done. This study focuses on two diverse age groups (fourth and eleventh grade) and also on different levels of intellectual ability (gifted and non-gifted).

Researchers are currently suggesting that a student's status of perconceived knowledge may be a more meaningful measure of learning potential than any other presently recognized standardized means (Lochhead & Clement, 1979; Viennot, 1979). A review of research by Renzulli (1978) suggests that the determination of a priori giftedness based solely on preordained standards and results on standardized tests may overlook bright children capable of high levels of achievement in certain areas of intellectual or non-intellectual endeavors. Sternberg (1982) has shown that determination of giftedness based solely on arbitrary cut off points on test scores results in serious problems of underidentification of the gifted students. Sternberg feels that, while test scores may be informative in a percentage of the cases, they may be useless in other cases for determining giftedness. Research indicates that there is a drifting away from using test scores as the only criterion for determining giftedness (Resnick & Glaser, 1976; Sternberg & Rifkin, 1979); however, schools in this country continue to utilize an extensive and detailed psychometric evaluation of their students for placement in the gifted program (Sternberg, 1982). The basis for identification of these groups has traditionally been numerical scores on standardized tests. In Pennsylvania, for example, 130 or above on either the Wechsler or Stanford-Binet is considered gifted. A need to examine abilities other than those measured on an I.Q. test is becoming apparent. Getzels and Jackson (1962) and Torrance (1959) among others have shown that many potentially gifted children are, in fact, below 130 I.Q. Guilford (1967) has also stated that if I.Q. alone is used to identify gifted students, many children will be missed.

The research of the last 30 years has shown that I.Q. is not necessarily synonymous with intelligence and that I.Q. is merely a simplification of a complex superstructure of cognitive abilities (Carrol, 1978; Guilford, 1967;

Sternberg, 1983). Guilford's (1967) famous "Structure of Intellect Theory," which utilizes a factor-analytical model, recognizing 120 specific intellectual factors, is evidence of our increased appreciation of the complexities of human intelligence. The psychometric approach to understanding intelligence which understandably has great appeal to some researchers is currently meeting with disenchantment (Carrol, 1978; Sternberg, 1982). An examination of preconceived knowledge may provide educators and learning theorists with an additional window for looking at giftedness and intelligence.

Purpose of the Study

The purpose of the present investigation is (1) to identify and confirm the existence of a non-Newtonian view of certain mechanical concepts among elementary and secondary students as previously detected by several researchers in other age group populations (Champagne, Klopfer, & Gunstone, 1982; McCloskey, Caramazza & Green, 1980; McDermott, 1984); (2) to test the relationships between preconceived knowledge and giftedness as defined by the local school district for the elementary and the secondary sample groups.

Statement of the Problem

Questions

The central questions of this study ask:

(1) Is preconceived knowledge of mechanical concepts of gifted learners from diverse levels of cognitive development significantly different from that of non-gifted learners? This comparison will be made on the basis of 14 individual questions and tasks.

(2) Do formal thinkers have fewer misconceptions concerning mechanical concepts than pre-formal thinkers?

Hypothesis

The problem statement is "translated" into the following null hypotheses:

H1. There is no significant difference in the levels of preconceived knowledge concerning certain mechanical concepts between gifted and non-gifted students.

H2. There is no significant difference in the levels of preconceived knowledge concerning certain mechanical concepts between formal and pre-formal thinkers.

Methodology

The samples chosen for this study included gifted and non-gifted students in the fourth and eleventh grades. Giftedness was defined by the policy of the school district. To establish their Piagetian level of intellectual development, a test was administered to each group. The fourth grade was chosen because the literature indicated most would be concrete operational and able to understand the instructions needed for the preconceived knowledge portion of the study. The secondary-level sample was chosen from the eleventh grade for two reasons. The first was the literature supports the assumption that the majority of these students have achieved formal operationalism. The second reason was that physics is offered in the eleventh year in the site school district and all the eleventh-grade students in the gifted and non-gifted samples were taking a similar physics course during this study.

The instrument used in this study to measure preconceived knowledge of certain mechanical concepts (see appendix) was derived from specific questions and problems used by researchers examining preconceived knowledge among diverse age groups. The suitability of the questions chosen was determined by a pilot study.

Assumptions

For the purpose of this study the following assumptions are made:

(1) that the techniques of clinical interviews used to measure concrete operationalism based on Piagetian protocol and demonstrated by Reisman and Torrance (1978) are valid;

(2) that the scoring of the Piagetian tests used to determine concrete and formal operationalism are based on accepted and validated methods;

(3) that the questions and exercises used in the preconceived knowledge test based on the protocol utilized by Champagne, et al. (1980), Clement (1982), and McCloskey (1983) are valid;

(4) that the students tested understood the instructions and answered honestly;

(5) that the methods and criteria used for placement in the gifted program were applied consistently and uniformly across the entire research population;

(6) that the physics course taken by the gifted and non-gifted eleventh grade samples was similar for all students.

Delimitations

The degree to which the results of the present study may be generalized has the following delimitations:

(1) The study was limited to a single public school district located in northeastern Pennsylvania in a predominantly white, middle-class, suburban community with common socio-cultural attributes.

(2) The fourth grade non-gifted sample used in this study represented a random cross section of the non-gifted fourth graders in the site district.

(3) Only those criteria for identifying gifted students as established by the specific school district under study were considered.

(4) The study was limited to two definitive populations which included gifted and non-gifted students. The sample, however, did not include the measured lower levels of cognitive abilities.

(5) The study did not include any differentiation in sex as a variable.

(6) This study purposefully did not consider creativity as a variable.

(7) Only those eleventh graders who were taking physics were included in the study.

Limitations

The limitations of the present study are as follows:

(1) Those fourth grade students in both the gifted and non-gifted samples who could not demonstrate successful concrete operationalism according to the Piagetian protocol (Trojcak, 1979) were eliminated from the study.

(2) Those eleventh grade students in both the gifted and non-gifted samples who could not demonstrate successful formal operationalism according to Piagetian protocol (Renner & Stafford, 1972) were eliminated from the study.

(3) Only those students who were identified as gifted students using the criteria established by the site school district were included in the gifted samples.

(4) Gifted and non-gifted eleventh grade students who were not taking physics concurrently with this study were not included in the study.

(5) No consideration was given to any other academic training or preparation except for the same physics course taken concurrently by all members of the eleventh grade population.

Operational Definitions

Aristotelian Mechanics:

Belief that an object is capable of motion only so long as it is in contact with an external mover. Rest is a natural state and objects which are undergoing motion seek to return to that state.

(Dijkterhuis, 1961)

Impetus Theory:

An extension of the Aristotelian model, it provides for the properties of motion to be imparted to the object by the mover and in the direction intended by the mover. The object comes to rest only after the impetus which has been imparted to the object is dissipated.

(Butterfield, 1965; Clagett, 1959)

Newtonian Mechanics:

Constant linear motion (constant velocity) is possible without the presence of unbalanced forces. If an unbalanced force is present, the body will undergo a change in its state of rest or constant motion (inertia) which is called acceleration; and the acceleration will be in the same direction of the force.

(Halliday & Resnick, 1981)

Preconceived Knowledge:

Specific questions and problems derived from previous research were used to construct an instrument to measure the nature of preconceptions dealing with mechanical concepts held by elementary and secondary students in the samples studied. Their levels of preconceived knowledge were determined by individual scores on this test.

Giftedness:

(a) The bureaucratic definition utilized by many states, including Pennsylvania, stresses the psychometric criteria such as I.Q. and achievement test scores. These standardized

tests emphasize demonstrated performance and predicted capabilities.
(Guilford, 1967; Renzulli, 1978)

(b) All those designated as gifted in the sample population were those who scored 130 or higher on the Stanford-Binet I.Q. Test administered in the first grade. This was the sole criterion for placement in the gifted program and is determined by school district policy.

Mechanical Concepts:

For purposes of this study, mechanical concepts refer specifically to free fall, pendulum, and projectile motions, relationship between forces and motion, circular motion, and the way students apply these concepts in explaining personal experiences.

Summary

A review of major national studies show there has been a decline in the average science achievement for the nation's youth over the last 15 years, particularly in the physical sciences (National Science Foundation, 1980). Several reasons have been advanced to explain this decline; however, those most commonly mentioned include a diminished seriousness of purpose in the learning process and a diminution of motivation among students (College Entrance Examination Board, 1977). Researchers agree that the principal vehicles available to science educators to address this problem are instruction and curriculum (Champagne, et al., 1980; Renner, 1978). The frustrating aspect of this situation is that high expenditures on curriculum reform have not reversed these trends. Federally sponsored curriculum development programs were an essential strategy for improving science teaching in the post-Sputnik era. Studies have shown these curricular innovations benefited a very small group of students who intended to pursue careers in science and engineering (Welch, 1979). The majority of students who did not intend to pursue such a career were vitually ignored. Present surveys indicate this is still the case (NSF, 1983). Current research in science education has, as a main focus, significance of preconceived knowledge to the learning of science. Studies in this area have shown that the knowledge gained about students' preconceived ideas is aiding in the development of innovative instructional strategies (McDermott, 1984; Minstrell, 1984). Educational psychologists have also studied preconceived knowledge in an attempt to formulate an expanded model of learning (Champagne, et al., 1980; McCloskey, et al., 1980) and as a model for viewing giftedness (Ausubel, Novak, & Hanesian, 1978; Peters, 1982; Renzulli, 1957; Torrance, 1959). Regardless of the motivation behind the research, the results have contributed to a growing body of knowledge of the difficulties students encounter in learning physics and the significance of their preconceived views to these learning difficulties (McDermott, 1984).

Research on the nature of preconceived knowledge in the physical sciences and on its implications to science learning has provided an exciting new perspective for viewing giftedness, particularly as it relates to the learning of science. The present investigation has attempted to expand the model of giftedness by examining preconceived knowledge dealing with mechanical concepts in gifted and non-gifted students on both the elementary and secondary levels.

Conventional testing in the sciences has traditionally emphasized isolated facts and empirical relationships. It has generally been assumed that gifted students demonstrate more advanced cognitive abilities, such as problem-solving, than the average student of the same chronological age (Stanley, George, & Solano, 1977). The results of the present study may help determine whether some cognitive abilities, such as those associated with the structuring and internalizing of preconceptions dealing with mechanics, may not develop spontaneously, simply as a concomitant of the advnaced intellectual development associated with higher I.Q. scores. Also, the present study may show whether the perceptions of the physical world held by most students are based on more than the level of intellectual development, cognitive skills, or the amount of formal science instruction received.

Apparently one cannot consider the student to be neutral or innocent in his/her appreciation of the mechanical world. The concepts taught in the classroom find resistance and sometimes total rejection resulting from stable preconceptions that students have constructed over a number of years of interacting with their environment. The present research, supported by the following literature review, is intended to increase awareness for a possible expanded or new model of giftedness which may include preconceived knowledge as one of the criteria to be included in the determination of giftedness. It can also aid in the development of instructional strategies which enhance a correct understanding of science concepts on the part of the student, rather than their rejection which the literature indicates is currently the norm.

Chapter 2

REVIEW OF THE LITERATURE

Victor Weisskopf, a colleague of men like Einstein, Bohr, and Fermi, is a living witness to the emergence of the Atomic Age. He writes and lectures extensively on the need for humanism in our appreciation of science. Weisskopf continues to be interested in how man comes to know and appreciate the order and symmetry of the physical world. Further, he makes the point that the fundamental concepts essential to the understanding of the physical world are abstract and seemingly far removed from everyday experience; however, Weisskopf contends these experiences continue to serve as the principal source of information upon which one constructs his conception of the physical world (Weisskopf, 1976). "Physics is simple, but subtle" (Weisskopf, 1983). Young children see an event and simply explain it; failure to appreciate the subtleties of cause and effect create within the child's mind those preconceived ideas which are the basis for the future science learning problems recently identified (Wittrock, 1977). Studies by Champagne et al. (1980), Gilbert, Osborne and Fensham (1982), McCloskey (1983), McDermott (1984), and others have shown that student held preconceptions are not only logical and coherent to the students but extremely resirtant to change. Boulanger and Kremer (1981) have demonstrated that past learning, rather than cognitive ability, is the best predictor of future learning. Wittrock (1977) demonstrated that students develop perceptions concerning the physical world which are consistent with prior learning. Eylon and Reif (1980, Champagne and Klopfer (1980), and others found that preconceived views can either facilitate or hinder the sequential development of science concepts. Science educators and learning theorists have become intensely interested in how students come to hold and use their preconceived views in explaining their experiences.

The specific focus on this study is to examine the preconceived views of mechanical concepts among gifted students and possibly to expand, change, or redefine our model of giftedness to include this information. Bloom (1976) indicated that 50% of the variance in school achievement can be traced directly to cognitive abilities which involve prior knowledge. The present study is an outgrowth of research in several areas which include: (1) the nature of students' preconceived views and the ways these views influence the learning of science; (2) the models of learning and cognitive development that impact upon the science learning experience; (3) the models for assessing intellectual ability and methods for identifying the gifted student. This researcher examined preconceived knowledge concerning certain mechanical concepts among gifted elementary and secondary students. In order to provide a theoretically sound background for the focus of this study, a review of the literature incorporates and addresses three general areas of interest: (1) a historical review of mechanistic models from the Aristotelian to the Newtonian views and how these views have influenced our perceptions of the world; (2) a review of the research on learning theory and cognitive development which relate to the learning of scientific concepts; (3) a review of the research dealing with student-held views and the ways these views can influence the learning and teaching of science.

The Mechanical World

Philosophical Aspects

Early Views of Motion

The importance of understanding motion for an appreciation of our mechanical world is outlined in Herbert Butterfield's (1965) influential book, The Origins of Modern Science, 1300-1800. The author suggests that "of all the intellectual hurdles which the human mind has been faced with and had overcome in the last fifteen hundred years, the one which seems to me to have been the most amazing in character and the most stupendous in the scope of its consequences is the one relating to the problems of motion . . ." (p. 3).

The early writings dealing with ancient natural philosophy indicate a preoccupation with motion. The scholastic adage, *Ignorato motu ignoratur natura* (Who knows not motion knows not nature) was a common theme in the writings of the Eleatic, Atomistic, Platonic and Aristotelian Schools of Natural Philosophy (Holton, 1973). The Aristotelian view, which dominated natural philosophy for 2,000 years, portrayed motion as a transition from potentiality to actuality. This view included a generalized definition of motion. *Motes estactus entis in potentia secondum quod in potentia est* (Motion is the actuality of that which is potentially viewed from the standpoint of potential being) (Butterfield, 1965). Holton (1973) suggests that Aristotle's concept of motion was allegorical; that is, local motion held a predominant position in science because all other motion could be reduced to it. In the context of present knowledge the concept of motion is central to our understanding *fields* and the propagation of energy. Science has continued to progress by resolving the most complex phenomena into their constituent forms of local motion (French, 1971).

Pre-Newtonian concepts of causation of motion perplexed most observers; these concepts were multicausational. One of these involved the idea that, when objects were propelled, they continued to possess this innate property for continued motion. This was known as the impetus theory (Holton, 1973). Galileo, in one of his dialogues on motion, also endorsed the impetus theory (Drake, 1967). "I have put forth the observation of the pendulum so that you would understand that the impetus acquired in the descending arc is able by itself to drive the same ball upward by a forced motion of the ascending arc" (Galileo, 1590, Translated by Drake, 1967, p. 227). The philosophical view of the mechanical world prior to the 17th century was dominated by the "impetus theory," which developed as a medieval modification of the Aristotelian view of motion (Gamow, 1961).

The impetus theory found popular support throughout the Middle Ages and formed the basis for the explanation of all motion from throwing a stone to tracking a planet across the sky (Poincaré, 1929). The Greek philosopher, Philopomus, writing in the 6th century, and the French philosopher, Jean Buridan, writing in the 14th century justified motion in the physical world with the "impetus" theory (Clagett, 1959). Buridan's concept of the impetus theory was the most commonly held model of philosophers and scientists of the Middle Ages. He stated:

> "When a mover sets a body in motion, he implants into it a certain impetus, this is, a certain force enabling the body to move in the direction in which the mover starts it, be it upward, downward, sideward or in a circle. It is because of this impetus that a stone moves on after the thrower has ceased moving it."
> (Clagett, 1959, p. 107)

The impetus model was a medieval extension of the Greek view of motion and added a critical component: external causation. The Aristotelian view held that in order for an object to experience motion a continuous and external force must exist (Eddington, 1928). This idea made it difficult to justify the motion of even a seemingly simple example like a projectile. Once it leaves the hand of the launcher, which is the source of motion, what unseen force returns it to the ground? The impetus theory solved this problem for it assigned an internal source of motion to the object. It was thought this internal force, stored within the object at the instant the object was propelled, was responsible for the continued motion. This internalization of stored motion was the essence of the impetus theory (Russell, 1945). Since objects do eventually stop, it was believed that the impetus must dissipate itself over time; and this explained how things came to rest (Holton, 1973). The justification of all motion required the impetus to be dissipative since all things come to rest. The history of mechanics during the Middle Ages describes a model which shows a projectile shot into the air initially in a straight upward path until the impetus has been depleted and it subsequently falls in a straight line to the earth under the impetus of its own weight (Dijksterhuis, 1961).

Interestingly, the impetus theory was not confined to linear motion; examples of circular and rotational motion were also justified with this idea. It was an observed fact that a hoop or wheel set in motion continues to roll after it has been released. The apparent circular motion of the planets, the sun, and the stars was also considered evidence for the impetus theory (Russell, 1945). Leonardo da Vinci also subscribed to the idea of the circular impetus. In describing how an object would depart after having been swung around in a circle and released, he stated,

> "Everything movable thrown with fury through
> the air continues the motion of the mover;
> if, therefore, the latter moves in a circle
> and releases it in the course of this motion,
> its movement will be curved."
> (Feigl & Brodbeck, 1953, p. 214)

In spite of a misguided view concerning motion, the scientific discoveries of the period stretching from the Greeks to the Renaissance are many and great. They include the discoveries of Ptolemy, Euclid, Hero, Archimedes, Brahe, Kepler and Copernicus, to mention a few (Gamow, 1961). While most of the mechanical concepts developed during this period were subsequently rejected by Newtonian mechanics, other discoveries in optics, thermodynamics, and astronomy made during this period continue to impress the intellect of even the most sophisticated modern physicist. Interestingly, their flawed view of simple motion as throwing a stone demonstrates the subtle and complex concepts involved in understanding motion (Einstein & Infeld, 1938; Russell, 1945).

The Newtonian concepts presently taken for granted are by no means obvious to even the brightest of minds. Even Galileo, the father of modern physics, in his early writings used the impetus theory to describe the motion of a falling object (Clagett, 1959). It took the genius of a Newton to build a new mechanical view of the world based not on the animistic view of the impetus theory but rather on an advanced mathematical basis which introduced the quantitative description of external forces affecting motion (Russell, 1945). The following section will consider the mechanical view of the world proposed by Isaac Newton.

Newtonian Mechanics

The animistic, philosophical view of the physical world put forth by the Greeks and the "impetus" concept which evolved in the ensuing years of the Middle Ages dominated man's thinking about his world for over 2,000 years (Butterfield, 1965; Einstein & Infeld, 1938; Holton, 1973; Russell, 1945). However, as the Renaissance movement of the 1500s spread across Europe it brought with it changes in attitudes toward the arts and religion as well as science. Examples of outstanding contributions to this period were made by Gutenburg, da Vinci, Michelangelo, Raphael, Luther, and Calvin (Crombie, 1959). Within this emerging cultural rebirth lived Mikoli Kopernik (Copernicus), an outstanding Polish astronomer. In 1543, the year of his death, he gave permission for the publication of his revolutionary and controversial book, On the Revolution of the Heavenly Spheres. In it he revived the sun-centered solar system postulated by Aristarchus nearly 2,000 years earlier (Gamow, 1961). The importance of the change in perspective was that Copernicus gave us a new way to consider the old observations. Feynman (1963) writes that a new theory can usually lead to new observations or new uses of old data. In this way Copernicus' ideas acted as a springboard for other scientists and launched a transition period which became a bridge between the Aristotelian model and the mechanics of Newton (Project Physics, 1980).

Other important contributions to this transition period were made by Kepler and Galileo working on problems of planetary motion. While Kepler confined most of his interest to astronomical motion of the stars and the planets (Russell, 1945), Galileo, forbidden by the Inquisition to pursue heavenly interests, gave his attention to the motion associated with ordinary objects like that of a pendulum or a ball rolling down an inclined plane (Taylor, 1941). The genius of Kepler was evident in his ability to extrapolate from an enormous body of observations and measurements made by his friend, 16th century Danish astronomer, Tycho Brahe, and to summarize them as follows:

> 1. The planets move in ellipses having the sun at one focus.
> 2. The line joining the sun to a given planet sweeps out equal areas in equal times.
> 3. The square of the planet's year divided by the cube of its mean distance from the sun is the same for all planets.
> (French, 1971, p. 5)

Known as Kepler's Laws of Planetary Motion, the foregoing represent a magnificent advance in man's knowledge of the mechanics of the heavens (Dijksterhuis, 1961). The most notable feature of Kepler's Laws was that they suggested elliptical orbits for the planets around the sun. Russell (1945) stated that the abandonment of circular motion in the heavens, which governed astronomy for nearly 2,000 years, for the non-aesthetic ellipses suggested by Kepler was an emancipation from tradition greater than modern man can easily realize. No ancient, not even Aristarchus of Samos, could have anticipated such a hypothesis (Holton, 1973).

As a result of the model of planetary motion proposed by Copernicus and Kepler, the understanding of mechanical events moved from philosophical justifications to mathematical and geometric descriptions. However, Kepler's Laws were still not a theory of motion but rather a description of motion (French, 1971). The world would have to wait for Newton to synthesize the ideas of motion into a comprehensive theory (Russell, 1945).

Galileo, a contemporary and friend of Kepler, was perhaps the greatest of the founders of modern science, with the possible exception of Newton. Born in 1564, he discovered most of the experimental bases for present-day mechanics and dynamics, and his work gave substance to Kepler's hypothesis while paving the way for Isaac Newton (Gamow, 1961). Galileo was the first to observe the law of falling bodies and to introduce the concept of changing motion. Galileo also experimented extensively with the simple pendulum and rolling objects down inclined planes. As a result of these experiments, he was able to show that all objects behave in the same manner independent of their mass. In addition, Galileo was an advocate of the sun-centered solar system in the best Copernican tradition and consequently believed in the intrinsic order of the universe (Butterfield, 1965). He applied this sense of universal order to the motion of ordinary objects and was able to demonstrate in his "Dialogue Concerning the Two Chief World Systems" (1632) that the motion of falling and rolling objects was predictable and based on an external force such as gravity and not on an internal factor such as mass. Galileo's work shifted the focus from idosyncratic causes of motion to universal laws (Holton, 1973).

Men had observed the motions in the heavens and on earth from the beginning of time. They had learned to predict certain regularities like eclipes of the sun and moon, yet could not understand how a stone fell to the ground. The contributions made by Copernicus, Kepler, and Galileo paved the way for the final and complete synthesis achieved by Isaac Newton (Russell, 1945). Nearly 20 years after his original solutions, Newton consented to publish his *Philosophiae Naturalis Principia Mathematica* (1687), in which he literally "framed the system of the world." The *Principia* has served as the primary basis for our understanding of classical mechanics for 300 years. As further proof of its universality, Einstein saw fit to incorporate Newton's premises for non-relativistic motion in his "General Theory of Relativity" (Einstein, 1905). Newton's achievements in classical mechanics were hailed as the greatest discovery of all time. Alexander Pope, an admirer and contemporary of Newton, immortalized this feat in his famous couplet:

> Nature and nature's laws lay hid at night.
> God said, "Let Newton be, and all was light."
> (Pope, 1698)

Since one of the most prominent features of the universe is motion, René Descartes, the 17th century French philosopher, put it best when he said, "Give me matter and motion and I will construct the universe" (French, 1971, p. 3). There can be no doubt that the understanding of motion is essential to our understanding of the world around us. Whereas the Greeks and medieval natural philosophers utilized an internal source of motion characterized by the "impetus," Newton developed a precise and powerful theory regarding motion. He proclaimed that changes in motion of any object are caused by external forces acting externally on the object (Butterfield, 1965). This was a landmark in the history of science, for it replaced a descriptive and qualitative account of an action with a rational, quantitative, and marvelously successful scheme of cause and effect (Holton, 1973).

Classical Newtonian mechanics have evolved into an intricate, abstract, and symbolic representation of what otherwise might be considered "ordinary" motion, like the falling of an object. It is this latter side of physics to which students are all too often exposed (Clement, 1982; Renner & Lawson, 1973).

According to French (1971) it is not all that remarkable that the flight of a thrown pebble should contain the clue to the mechanics of the heavens, namely, the law of gravitation. Though we present mechanics as if it were merely the routine applications of self-evident or obvious truths, French (1971) states that nothing could be further from the truth; it is a superb example of a physical theory gradually refined as we bring observations and hypotheses together.

By the 1700s, the Age of Reason had reached its pinnacle with Newton's new cosmology; the Aristotelian and impetus models of motion were finally dethroned by the Newtonian model (Project Physics, 1980).

George Gamow (1961) in his *Biography of Physics* outlines the salient issues addressed in Newton's Laws of Motion. Before Newton actually formulated these laws, he defined the concepts of *mass*, *momentum*, *inertia*, and *force*. Gamow (1961) extracting these definitions from several translations offers the following as examples:

(1) MASS - the product of an object's density multiplied by its volume

(2) MOMENTUM - the product of an object's velocity (as defined by Galileo) multiplied by its mass

(3) INERTIA - the tendency of an object at rest to remain at rest and an object which is in constant motion to remain in constant motion

(4) FORCE - an action exerted on a body in order to change either its state of rest or uniform motion (Gamow, 1961, pp. 54-55)

Having defined the concepts of mass, momentum, inertia, and force, Newton proceeded with his formulation of the fundamental laws of motion:

1. Every body continues in its state of rest or uniform motion in a straight line unless acted upon by an outside force.
2. The change in momentum of an object either in magnitude or direction is proportional to the force exerted on the object and will be in the direction of the force.
3. To every action or force will be an equal and opposite reaction.
(Newton, 1687, tran. by Motte, 1934, p. 13)

Newton, in his Principia Mathematica Philosophiae Naturalis (1687), laid down the entire construct for the mechanical laws describing all physical phenomena. These fundamental concepts of motion and the mechanical perspective of the universe advanced by Newton are so mathematically precise that they dominated physics until the beginning of this century and continue to the present time to form the basis of classical mechanics and our understanding of the motion of ordinary things (Russell, 1945; Whitehead, 1968).

The impact of Newton's achievements were felt in science, philosophy, theology, and even in politics; namely, in the thesis that by observing and reasoning, by considering mechanical models and deducing mathematical laws, one could discover the workings of the physical universe (Whitehead, 1968). John Locke (1690) applied the Newtonian model to problems in philosophy, religion, and politics. Locke's tabula rosa concept as it applies to the mind of a child was a direct result of the Newtonian idea; that is, one must look to nature for information concerning the world. However, during the same period there were many philosophers who attempted to discredit the Newtonian view of nature, including Goethe and other Romantic writers such as Blake, Coleridge, Shelley, and Byron. Exalting the humanistic model of nature, these men scorned the mathematical view of nature for they abhored the "clockwork" model of the universe advanced by Newton (Jaki, 1969).

Although the assault on the Newtonian model continued throughout the 18th and 19th centuries, its success in explaining the physical universe became evident to even the strongest skeptic and could not be ignored. Newton's Laws continue to stand as a cornerstone of our understanding of our mechanical universe (Butterfield, 1965).

Summary

The literature describing the ancient views of the physical world is primarily historical and philosophical. It characterizes the Aristolelian model of motion as requiring an external force to produce all motion. The only natural state for terrestial matter is rest. This view of an immutable mechanical world dominated thinking in Europe for over 2,000 years. Aristotelianism was characterized by an intuitive logic which was perceived as congruent with observations. A variation to the Aristotelian model introduced in the Middle Ages was the "impetus" model; it assigned an animate force or energy to all moving objects which kept them going until this "impetus" dissipated as objects came to rest.

Galileo, in the 17th century, extrapolating from the cosmic generalization of Copernicus and Kepler, analyzed the motion of earthly objects and helped set the stage for the great Newtonian synthesis of all motion under a single set of comprehensive empirical laws. The Newtonian revolution presented us with a model for motion which involved a changing velocity and the ideas that constant motion required no external force. The antithesis of this idea was that, if a force were present, the object must experience a change in velocity (acceleration). Newton viewed rest and constant motion as equivalent states, a view abhorrent to the ancient Aristotelian view. However, the difference between the Aristotelian and Newtonian views is by no means trivial. The following section will further delineate these differences and will examine how students come to hold views about their world which more closely resemble the Aristotelian than the Newtonian model.

Scientific View

Newton's Mechanical Universe

At the time Newton was born, the world still tenaciously held the Ptolemaic view of an earth centered solar system. Championed by the Church in Rome, this view began to yield to those philosophers and scientists in northern Europe who advanced the Copernican heliocentric model refined by Kepler.

In 1665, the plague struck Europe and the major universities were closed. At 23 years of age, Newton found himself once more at his mother's home in Wollsthorpe after Cambridge University closed its doors. He spent several years there in lonely solitude, contemplating the works of Copernicus, Galileo, and Kepler. Newton, endowed with a flare for mathematics, sought to frame a model of the world which would encompass all the observations and theories made to that point in time. According to most science historians, this was the time of the famous and disputed fall of the apple (Holton, 1973). Newton, seeking to understand and explain the elliptical shapes of planetary motion predicted by Kepler, as well as ordinary terrestial motion as described by Galileo, framed the "Law of Universal Gravitation." Later, writing on his life, Newton (1687) referred to this period of discovery:

> I began to think of gravity extending to the orb of the moon, and . . . from Kepler's rule . . . deduced that the forces which keep the planets in their orbs must be reciprocally as the squares of their distance from the centers about which they revolve; and thereby compared the force requisite to keep the moon in her orb with the force of gravity at the surface of the earth, and found them to answer pretty nearly. All this was in two plague years of 1665 and 1666, for in those days I was in the prime of my age for invention, and minded mathematics and philosophy more than at any time since.

For nearly 20 years Newton kept secret his discoveries made at the Wollstrope farm during the plague years. It was not until 1684 that, at the urging of his good friend, Sir Edmund Halley, Newton finally consented to publish his work. With the publication of his Principia in 1687, Newton was quickly proclaimed one of the greatest thinkers of all times (Butterfield, 1965).

The Principia was an extraordinary document. It contained a wealth of mathematical and physical discoveries, but the richest revelations were those of universal gravitation and the three laws of motion. Essentially Newton was saying "Every object in the universe attracts every other object" and this attraction depends on the simple physical concept of mass and the geometric concept of distance. This was a great synthesis of the terrestrial laws of motion initiated by Galileo and the astronomical laws of motion initiated by Copernicus and Kepler (Holton, 1973). According to Newton the same law which explains the motion in the heavens also applies to a pebble thrown through the air or an apple falling from a tree. Heaven and earth were now united in one grand system by this son of an illiterate farmer.

Using Kepler's Laws of Planetary Motion, Newton was able to conclude that the force between the sun and the planets varied inversely with the square of the distance between them and directly with the product of their masses. With the addition of the proportionality constant measured by Cavendish nearly 100 years after Newton, the Law of Universal Gravitation takes the following empirical form:

$$F = G \frac{M_1 M_2}{D^2}$$

Where F is the gravitational force between the two masses, G is the proportionality constant; M_1 & M_2 are the respective masses of any two bodies (i.e., the sun and a planet); and D is the distance between their centers. This new universal perspective for analyzing motion began to unlock the mysteries of motion which had bewildered philosophers and scientists for centuries (Russell, 1945). Newton did "frame a system of the world" in the *Principia* (1687) with the introduction of the physical abstraction he called "The Universal Law of Gravitation." He also laid down the theoretical basis for all mechanics which is known as "Newton's Three Laws of Motion."

These three laws that bear Newton's name appear to be simple statements. Their profound value derives precisely from their elementary simplicity and consequent generality. Jacob Bronowski (1973) in his *Ascent of Man* said, "All science is the search for unity in hidden likenesses." It is this comprehensive unity, this ability to encompass all theories and observations into one framework, that lends Newton's work its magestic beauty.

Newton's First Law of Motion contains two separate statements. The first--that a body at rest will remain at rest unless acted upon by an external force--is not only consistent with everyday experience; it is also in accord with the Aristotelian belief that rest was a "natural" state for objects. The second, however, seems to contradict our everyday experiences. It states that, if an object is in constant motion in a straight line and there are no external forces on it (like friction), it will continue to do so. Newton perceives rest and constant motion as equivalent states.

His second law, expressed empirically as $a = F/M$, says that the acceleration (a) of a body depends only on the force (F) and mass (M); a larger force will produce a larger acceleration on the same mass. By choosing correct units we can rewrite this law as $F = Ma$; where M is measured in kilograms, acceleration is measured in meters/second/second and F is expressed in newtons.

The third law states that as an object exerts a force on a second object, the second object will likewise exert a force on the first object. This law differs from the first two because it involves two separate and distinct bodies (Halliday & Resnick, 1981).

Since ancient times the idea of a natural place and natural motion was used to explain the motion of things; the medieval thinkers added the concept of impetus, which implied that when an object was set in motion it would continue until this propensity for motion was depleted. However, to Newton the only natural motion was of an object moving in a straight line with constant speed. Motion in a curve required an external force keeping it from moving in a straight line. In the case of planetary motion, this central (centripetal) force was gravitation. In the case of terrestrial motion, these laws describe the interaction of masses and external forces and their interaction with each other. These laws demand a quantifiable formulation of distance, speed, acceleration, mass and force. Consequently, they make possible the prediction of all future motion when the starting point and initial velocity are known, in addition to knowing the force which acts on the object. Essentially, Newton had created a whole new quantitative approach to the study of motion (French, 1971).

What astonished Newton's contemporaries then and modern scientists even today is the fact that these laws are successful in predicting future states of all mechanical systems involving gravitation. The elegance of his mathematical proofs also still retain their original brilliance. We presently recognize, however, that Newton's mechanics are valid only within a well-defined region of physical reality. The discovery of quantum mechanics and the theory of relativity have demonstrated some of the inaccuracies and limitations of his model. At the turn of the century with the discovery of the atom and electromagnetic radiation, these new theories marked a precipitous break with the fundamental postulates of Newton. The modern physicist in attempting to describe the behavior of electromagnetic waves recognizes that a truly immovable center of the world, the absolute rest frame, is not possible. However, this notion was fundamental to the ideas put forth by Newton (Halliday & Resnick, 1981). In spite of the fundamental distinction between non-relativistic Newtonian mechanics and Einsteinian relativistic mechanics, Newton's mechanistic view of the world continues to serve us in the comprehension of ordinary motion obvious to us in our everyday experiences. Furthermore, we should not forget that both the quantum mechanics of Planck and Bohr and the relativity of Einstein and Poincare are well rooted in the mechanical laws of Newton. Einstein used as his first postulate for developing the special theory of relativity that Newton's Laws are the same in all inertial frames of reference. Newton's Laws served as one of the pillars of support for the less specific theory of relativity (Einstein, 1938; Gamow, 1961; Holton, 1973).

Newton's mechanistic view of nature was so successful that it changed the way we perceive the world for all time. However, students of science from elementary to college level continue to struggle with the relevance of Newton's Laws to everyday experiences. Current research studies indicate that in spite of intense instruction in Newton's Laws, students tenaciously hold to views more resembling the pre-Newtonian "impetus" model in order to make sense of their physical world. A review of the literature dealing with these non-Newtonian views held by students indicates a child's learning patterns are influenced by these views. The research further indicates that this influence tends to be more negative than positive (Champagne, et al., 1980; McCloskey, 1983; McDermott, 1984). The following section will examine the nature of student-held views concerning the physical world and the way these views influence the learning of science.

Prevailing Non-Newtonian Views of the Physical World

Piaget (1929) described the process wherein children ascribe to inanimate objects the properties of living things; he called this process "animistic thinking." Watts (1983) has shown that children commonly utilize this process in attempting to comprehend their world. Gilbert et al. (1982) used the expression "children's science" to represent those physical constructs held by children. There is growing interest in the status of a child's preconceived knowledge in science as a basis for science education. Recent studies have shown that the preconceived views children bring to the classroom are complex and well-structured systems and are extremely resistant to change in spite of intensive instructional intervention (Champagne, et al., 1980; Clement, 1977; McCloskey, 1983; Nussbaum & Novak, 1976; Stead & Osborne, 1980).

Traditionalists in science education believe that preconceived views held by children are essentially incorrect and that the primary purpose of teaching is to "correct" them (Barnes, 1977; Donaldson, 1979). However, several current studies have shown that a "child's view" of the physical world is very important epistemologically and of high educational value and must be considered in the teaching strategy (Champagne, et al., 1980; Renner & Lawson, 1973; Watts, 1983). Pope (1980) recommends a "relationistic view" of knowledge which places a high value on personal knowledge. This view is consistent with Kelly's (1969) "constructive alternativism" concept. Kelly's position is that we all ultimately seek the truth and in so doing we assume things about our physical world. The events and experiences we face are all subject to as great a variety of explanations as our intelligence allows us to contrive.

An important goal of science educators has been to measure the level and sophistication of a child's view of scientific concepts (Watts, 1983). The personal interview using a case-study format has been successfully used in making these determinations (Champagne, et al., 1980; Gilbert & Osborne, 1982; Piaget, 1964).

An interesting dimension of this issue is that certain preconceived views dealing with motion are not solely held by young children in the concrete operational stage. McCloskey (1983), working with high school and college students, showed that they also hold strong misconceptions about physical phenomena and use pre-Newtonian concepts of motion to explain questions on motion. Other studies by Minstrell (1982), McCloskey (1983), and Champagne and Klopfer (1983) have shown that preconceived views of motion are held by students of diverse populations of age and intellectual ability. Since it would appear from the above studies that students from diverse groups hold persistent and well-formulated views of their physical world, it is essential that the constructs underlying them be identified and discussed openly and in great detail (Bruner, 1956; Piaget, 1954).

Several research groups have investigated the level of misconceptions dealing with a variety of mechanical problems. Champagne and others (1980) have studied student difficulties involving free fall. Clement (1982), McCloskey (1983) and Viennot (1979) have shown that students hold impetus-like beliefs in attempting to explain simple situations like throwing a coin straight up. Minstrell (1982) has reported student difficulties dealing with forces. Piaget (1970) and more recently Trowbridge and McDermott (1981) have shown that children and adults alike have difficulty understanding *distance*, *velocity*, and *acceleration*. One might think that errors caused by misconceptions dealing with mechanical concepts would reflect a wide variety of idiosyncratic views. The research indicates this is not the case. McCloskey (1982) interviewed college students, some of whom took physics and some who did not. What he found was 11 of the 13 students used a similar "impetus-like" view to explain mechanical problems. It was explained earlier how the impetus concept was introduced into the Aristotelian view during the Middle Ages (Butterfield, 1965; Dijksterhuis, 1961). According to this medieval theory an object set in motion acquires an internal force which is thought to keep it in motion. Caramazza, McCloskey, and Green (1981) have shown how students use their preconceived impetus-like view to explain pendulum motion. It appears that the students' choice of theory is a natural reaction to their experiences with motion in the real world (Clement & Brown, 1983; McCloskey, 1983).

It is an oversimplification to assume that these naively held misconceptions are merely a matter of incorrect information requiring simple remediation. The bulk of the research done indicates these views are complex, highly structured, resistant to change; and, most important, they enable a child to understand his experiences in the real world. In other words, THEY WORK!

Summary

The literature describing the ancient views of the physical world is primarily historical and philosophical. It characterizes the Aristotelian model of motion as requiring an external force to produce all motion. The only natural state for terrestial matter is rest. This view of an immutable mechanical world dominated thinking in Europe for over 2,000 years. Aristotelianism was characterized by an intuitive logic which was perceived as congruent with obuervations. A variation of the Aristotelian model introduced in the Middle Ages was the "impetus" model; it assigned an animate force or energy to all moving objects which kept them going until this "impetus" dissipated as objects came to rest.

Galileo, in the 17th century, extrapolating from the cosmic generalizations of Copernicus and Kepler, analyzed the motion of earthly objects and helped set the stage for the great Newtonian synthesis of all motion under a single set of comprehensive laws. The Newtonian revolution presented us with a model for motion which involved a changing velocity and the idea that constant motion requires no external force. The antithesis of this idea was that, if a force were present, then the object must experience a change in velocity (acceleration). Newton viewed rest and constant motion as equivalent states, a view abhorrent to the ancient Aristotelian view. The difference between the Aristotelian and Newtonian views is by no means trivial.

Summary: Scientific View

The history of natural philosophy is the history of man (Russell, 1945). Interest in the motion of the stars, the moon, and the planets preceded interest in the motion of ordinary things. This was due, in part, to the believed astrological implications of such motion which prevailed from the earliest time to the present. Stonehenge, built over 3,000 years ago, stands not only as an artifact of an ancient cult but also as a monument to man's respect for his physical universe.

The Aristotelian concept stated that all motion required some hidden force; and the medieval counterpart, the impetus concept, stated that all motion was somehow stored within a body. These ideas ruled man's thinking for over 2,000 years. As the knowledge of planetary motion increased, resulting mostly from the work of Copernicus and Kepler, interest shifted to the motion of earthly objects. Galileo was able to show that the motion of ordinary things, like rolling balls or swinging pendulums, also followed orderly and defined physical principles. Newton, drawing upon the philosophical ideas of Copernicus and Kepler, in combination with the experimental evidence accumulated by Galileo, was able to synthesize a masterpiece of theoretical abstraction. Through the application of mathematical analysis and deductive reasoning, Newton formulated the "Universal Law of Gravitation" and "Laws of Motion" which united all motion under one theoretical and philosophical model. Newton's discoveries caused all previously held concepts to become irrelevant or incorrect.

In spite of the universality of Newton's Laws, modern physicists have shown us that they are restrictive in their application. The discovery of the atom and the nature of light have caused us to change our perspective again. Nature is not just matter moving through space but includes the propagation of electromagnetic energy through space. The line separating matter and energy, particles and waves, time and space, is no longer distinct. There were no provisions in Newton's Laws to address these questions and new theories needed to be formulated. The physics of Planck, Einstein, Bohr, Heisenberg and others considered these physical realities and gave us a new mechanics: the mechanics of the atom and the propagation of light, namely quantum mechanics.

In spite of the great success the new mechanics experienced within this century, the fundamental importance of Newton's Laws is nevertheless intact both as a model for understanding motion and also as a basis for quantum mechanics (Einstein & Infeld, 1938). The quantum mechanics is necessary and useful in explaining how an atom behaves but relatively useless in explaining to a child how a ball rolls down a hill. Newton's laws are essential in comprehending the physical world with which we interact on a daily basis; however, research shows that few students actively use Newton's ideas to understand and explain their experiences. Instead, studies have shown that students, across all populations of age and ability, utilize a pre-Newtonian model which has proved to be resistant to change and greatly influences future learning. If this situation is to be remedied, the curriculum and the sequencing of concepts presented to our students may have to be modified. In an attempt to understand further this complex cognitive phenomenon the following section of the literature review discusses several learning theories and models of cognitive development and the ways they interface with the role of preconceived knowledge in the learning process.

Cognitive Development and Intellectual Growth

History of Learning Theory

Mental discipline theory dominated the early writings on learning. The question "How do we learn?" is as old as man himself and has always been a fundamental epistemological issue.

As an epistemological question, learning has been viewed both from theoretical and practical perspectives. The importance of the human intellect was evident in the writings of the early Greek and Latin philosophers. Socrates, Plato, and Aristotle believed the mind required exercise as do the muscles. They considered learning as the application of intellectual strength. Like most ideas of the early philosophers, their ideas on learning were dormant for over 1,000 years. However, the writings of St. Augustine and St. Thomas Aquinas, among others, revitalized the Greek models of learning. They professed the highest aim of man is the search for truth; the search for truth is a search for God; therefore, truth is eternal and perfect. Beyond the Greek dialectic method, these men put great stress upon the intuitive approach to knowledge (Ozman & Craver, 1981).

Rousseau and Pestalozzi in the late 18th century held that "sense impression of nature is the only true foundation of human instruction, because it is the only true foundation of human knowledge" (Ozman & Craver, 1981, p. 63). This was the beginning of an emphasis on human development rather than on learning. These early ideas on human development led eventually to the premise that environment has a part in making people what they are. This idea becomes an extension of the pragmatic philosophy known as associationism (Locke, 1691).

The ideas of associationism involved "any general theory within which it is assumed that learning starts with irreducible elements and the process of learning is one of combining these" (Bigge & Hunt, 1962, p. 277). An important contribution to the associationism school was made by two British philosophers, Thomas Hobbs and John Locke. They felt a person's learning is influenced by previous experience. Locke suggested one is born with a totally blank mind (*tabula rosa*) and nurturing rather than heredity is the basis for learning (Locke, 1691).

In the 19th century, further formulation and variation of the associationism concept evolved. Great emphasis, at this time, was placed on the "practical" side of education; the concept of "practical" included education for moral and character development as suggested by Herbert Spencer. Spencer in his essay, "What Knowledge Is of Most Worth?" held that science provides for both moral and intellectual education because the pursuit of science demands integrity, self-sacrifice, and courage (Ozman & Carver, 1981). Another offshoot of associationism was the theory of learning proposed by Johann Herbart who believed learning was made possible through the principles of frequency and association. Herbart's ideas formed the basis for many of the learning theories expounded in the early 1900s, subsumed under the stimulus-response school of psychology (Thornburg, 1984). Included among these is the school of realism. The realist's thesis of independent reality is similar to the behaviorist's belief that behavior is caused by environmental conditions (Ozmon & Craver, 1981). Scientific research dealing with behavioral learning mechanisms is generally recognized to have begun with Thorndike's work in 1898 (Thornburg, 1984). His discovery of the strong connection between the stimulus and learned response continues to serve as a cornerstone of modern behavioristic learning theory (Thorndike, 1932).

A dominant force in current behavioral learning theory is behavior modification. Watson in 1903 and Guthrie in 1940 were early innovators of the behaviorism school. Watson's work led him to conclude that emotional conditioning patterns exist among humans and that a reward is not necessary for learning (Watson & Rayner, 1920). Guthrie's theory of learning by association was an extension of Watson's work. Guthrie believed that we learn by doing and not by reinforcement or success and behavior could be replaced, but rarely broken or extinguished (Guthrie, 1952). Whereas Watson and Guthrie rejected Thorndike's law of effect, a prominent American learning theorist, Clark Hull, in the 1930s utilized Thorndike's ideas in formulating his law of primary reinforcement. Hull maintained learning takes place through conditioning and reinforcement. He felt when a drive-stimulus condition exists, it will precipitate a response and, consequently, will reduce the cognitive dissonance resulting in learning (Hull, 1943). Another theorist who advanced Hull's ideas on learning was Kenneth Spence (1951). Like Hull, he believed that habit strength depends exclusively on the frequency of the response; reinforcement is not necessary for establishing a stimulus-response bond.

A second major contribution to behavioral learning theory was made by Max Wertheimer (1938) nearly 30 years after Thorndike's animal experiments. A Gestalt psychologist, one who perceives all things being whole, Wertheimer saw the process of learning from a holistic view. Learning is acquired when we interact with our environment and internalize these interactions. Cognitive psychology has drawn much of its basis from Wertheimer's ideas on learning (Thornburg, 1984).

The current school of cognitive psychology, rooted in Gestalt theory, emphasizes the dynamics of learning and information processing. Major recent contributions to the cognitive school of learning have been made primarily by

Bruner and Ausubel. Bruner (1956) suggested that if a person has insight into this environment he will attach meaning to things, and through these meaningful relationships higher learning occurs. Ausubel (1968), like Bruner, believed that learning can occur only in a meaningful environment when the learner has purpose and direction.

The greatest departure in behavioral learning theory since the Hullian approach was championed by B.F. Skinner. Like Watson and Guthrie, Skinner (1952) believed that the strength of the stimulus-response bond depends on the conditioning of the response and the stimulus. While he supported Thorndike's idea of respondent conditioning, Skinner introduced the idea of "operant conditioning." He viewed this as a person's response to his/her environment; unlike respondent conditioning, operant behavior did not consistently require a specific or identifiable stimulus. Skinner's work has been very important to learning theory and consequently important to the science teacher. For example, his "knowledge-of-results" principle show us that the right answer wnen given is sufficient reward for a student (Skinner, 1968). However, since learning is a complex combination of many factors, the cognitive model of learning tends to be more useful than the more simplistic stimulus-response model (Ausubel, 1968; Bruner, 1971).

Albert Bandura (1977) describes learning of modeled behavior as a process that enables people to acquire large, integrated patterns of behavior without having to form them gradually by tedious trial and error. He stresses the rigidity of the reinforcement theory and advances a social learning theory that has greater flexibility, accounts for a wider range of social behavior, and gives credence to the individual's cognitive capacity. Social learning theory includes the concept of self-regulation, by which an individual exercises control over personal behavior by using self-reinforcement and self-motivation. The process of evaluating personal behavior and administering self-reward or punishment is the way to regulate and accept responsibility for one's own behavior (Biehler & Snowman, 1982). Students do not shy away from high standards, only from those they perceive as unattainable (Bandura, 1982). Several studies have found a relationship between internality (the belief that one is responsible for one's own successes or failures) and academic achievement. Students who attribute success or failure to external sources, such as chance, fate, teachers or powerful others, commonly show signs of lower academic achievement (Bandura, 1982; Nowicki & Walker, 1974).

An interesting variation of the stimulus-response model is the hierarchical model of learning advocated by Gagné. His theory emphasizes the orderly and cumulative nature of learning involving eight successive stages, each more complex where learning depends on the prerequisite knowledge or learning of a lower level (Gagné, 1970).

Robert Gagné describes the conception of learning endorsed by most American psychologists. In his book, The Conditions of Learning (1970), Gagné emphasizes verbal associations as a crucial element of learning; furthermore, he argues that the more advanced kinds of learning can take place only when a person has mastered a large variety of verbal associations. The Gagné model accounts for various types of classroom learning, more than most other contemporary learning theories (Thornburg, 1984).

Gagné (1980) also suggests that the current shift of learning theories from the older notion of connectionism (establishing S-R bonds) to a computer-based notion of information processing has some important implications for instructional strategies. The relationship between concepts and rules in Gagné's hierarchical approach to concept thinking is not only relevant and meaningful, but it accounts for the ways previously learned intellectual skills facilitate new learning. The importance of prior knowledge and its recall at the time of new learning continues to concern cognitive psychologists, especially those who are using contemporary theoretical models of learning and retention known as information-processing models (Bransford, 1979; Glass, Holyoak, & Santa, 1979; Mayer, 1975).

One of the more exciting learning models to surface recently is the information-processing model. This seems appropriate, somehow, during this computer age we presently find ourselves in. There are several models of information-processing; but all of them attempt to identify the range of variables affecting learning, memory, and retention. The major focus of these models has shifted away from the reinforcement models toward the cognitive domain utilizing the concepts of long-term and short-term memory and the way information is processed in order to have meaning for the learner (Bransford, 1979).

Summary

It seems probable that, as we know more about how our brain functions, our interest in how we learn will increase. Our world continues to become more complex, and meeting these challenges requires increased demands on our learning skills. Yet, in spite of these increased external pressures, learning remains a human and personal process; in whatever direction of theory or experimentation we move, the human dimensions of learning must never be ignored. Within the information-processing area, three models of learning emerge that have meaning for the science educator. They are considered in the next section.

Three Models of Learning

Developmental

Psychologists have identified various models of human development; these include the biological, emotional, social, moral, and intellectual. There is evidence to support the notion that these are mutually interrelated and the success in any one area may depend on the success in development within the other areas (Bloom, 1976; Piaget, 1971).

The importance of developmental psychology to learning theory has been cited in literature as early as the mid-19th century (Inhelder, 1972). Most learning theorists agree about the importance of readiness to learning but disagree as to how to structure educational programs to allow for differences in readiness (Lawson & Karplus, 1977). These differences of opinion have led to one of the major educational controversies of the decade. Psychologists such as Maslow and others felt children should be allowed freedom to progress at their own pace; however, Finner and his fellow environmentalists have argued that human development is too important to be left to chance and advocated the concept of guided development

(Biehler, et al., 1982).

Early work on natural readiness and developmental theory was done by Hilgard in 1932. Working with young children, he showed that general physiological maturation coupled with experience, other than specific maturation contributed to accelerated development of skills.

An opposing view of developmental theory was proposed by Lorenz in the late 1950s. Experimenting with animals, Lorenz (1957) showed that critical periods exist in development. An example of this is imprinting which occurs in animals during a very short period after birth and is unmodifiable thereafter. Similar work was done by Hebb (1949), Reisen (1958), and Thompson and Heron (1954). They showed that animals deprived of sensory stimulus would become permanently retarded. Spitz (1946), working with infants, suggested similar critical periods in the early development of human babies.

A model combining the readiness and critical-period concepts was advanced by Robert Havighurst (1953). Referring to developmental tasks, he suggested that specific tasks arise in certain periods of one's life and must be successfully negotiated in order to achieve happiness and to progress to higher tasks. Further, he observed, "When the body is ripe, and society requires, and the self is ready to achieve a certain task, the teachable moment has come" (p. 5).

There have been additional theoretical and experimental contributions to the developmental model. These include the "enrichment" theory of J. Hunt (1961). He stated, "If a lack of environmental stimuli caused retardation, then an enriched environment would accelerate intellectual development" (p. 103). Jerome Bruner (1960), writing in the early 1960s, assumed a position similar to that of Hunt. He postulated "any subject an be taught effectively in some intellectually honest form to any child at any stage of development" (p. 33).

Perhaps the best known developmental theorist was Jean Piaget. Born in Switzerland in 1896 and a zoologist by training, Piaget demonstrated an intense interest in epistemology which led him to study the nature and origins of knowledge (Inhelder & Piaget, 1969). In order to focus on Piaget's contributions, a brief digression is in order to consider the epistemological problem, one of the great imponderables which have engaged men's attention at least since the golden age of Greek philosophy. This problem of metaphysics has to do with the nature of reality and of our knowledge of it. Two schools of philosophy, empiricism and idealism, address this issue. Empiricism, on one hand, considers that all knowledge is derived from experience while idealism professes that knowledge is discovered (Russell, 1945). Man must search for truth. Truth is perfect and eternal and cannot, therefore, be found in the world of matter that is imperfect and constantly changing. This emphasis of idealism is considered by philosophers the most important factor in education at any level; that is, to teach students to think. Piaget, for example, has shown that it is not unreasonable to expect students to demonstrate some critical regard for the material they are exposed to at various stages of development (Ozman & Craver, 1981). Piaget clearly asked the more meaningful question, "How does knowledge develop and change?" As one can see, Piaget's epistemology is at once empirical--even experimental--and developmental in orientation (Piaget & Inhelder, 1969).

Piaget's work dealt with intellectual operations acquired by interactions between organism and environment and acquired in a lawful sequence (Tuddenham, 1966). Shayer and Adey (1983) make an important point about the nature of cognitive development described by Piaget that each stage of development includes those strategies of the preceding stage which have been found to be useful in modelling reality. Piaget's findings suggest that the child's preconceived knowledge can develop from the nursery tales that are read to him (Ozman & Craver, 1981).

Piaget's concern was with elucidating the sequence, *not* with establishing age norms for stages. He set out to write the ontogenetic history of cognition, excluding all that lies outside the cognitive domain. The innate equipment consists of reflexes present at birth. Some reflexes (yawning and sneezing) are relatively fixed and unmodifiable by experience, though some, like the Babinski, change with maturation. The majority of reflexes, for example, grasping, *require* stimulation for their stabilization, are modified as a result of experience, and constitute the basic behavioral units from which more complex forms of behavior emerge. Most important, the feedback from activation of a reflex alters all subsequent performance of that reflex. Thus, behavior is simultaneously determined by: (1) the inborn structure; (2) past activations, i.e., experience; (3) the particular present situation. Thus, the infant reflexes bloom into the world of the child in which not only objects, but time, space, causality and all the rest acquire a coherent organization (Piaget, 1929).

Joseph Novak, writing in the *Journal of the National Association for Research in Science Teaching* (JRST), states that a reason for the success of Piaget's developmental model is the power and consistency it possesses for critically observing selected educational events (Novak, 1979). He likens Piaget's technique to that of Mendel, who carefully selected specific traits and devised clever ways to record and transform data showing the consistency between theory and evidence (Novak, 1977b).

Piaget's theory of developmental learning is of particular importance to science educators (Renner, Grant, & Sutherland, 1978). According to Piaget, a child must first act upon his world as he sees it. Then he rearranges it, transforms it, and modifies it to form his own view of the world (Piaget, 1964). This information is intimately and personally drawn from the objects and their motion. This occurs during the concrete operational period and gradually develops into the formal operational stage when the student learns from the actions rather than from just the objects (Piaget, 1964; Renner, et al., 1978). The formal thinker, according to Piaget (1964), is an individual who thinks beyond the present and forms theories about everything, delighting especially in considerations of that which is not obvious. It is this learner who can visualize the abstractions of Newton's Laws. The literature indicates that science topics taught in our schools from the middle elementary grades through the college level are almost exclusively for formal thinkers (McCloskey, 1983; Renner & Stafford, 1972).

Piaget has stated that formal operational thought begins at 11 or 12 years. He did recognize that there might be differences in the norms for students from different schools or different social environments (Piaget, 1972). The common Piagetian attitude is that a majority of students reach the formal operational stage by 12 years of age (Piaget, 1964). The research of Renner and others (1978) seem to contradict this generalization. Their data indicate that 100% of elementary students, 70% of high school students and 50% of college students are exclusively concrete thinkers. Shayer and Adey (1983) asked, "Why does the ability to use formal operational thinking matter?" Their answer was (1) the human species does have brain-growth spurts which seem programmed to make possible this level of thinking in early adolescence; and (2) formal thinking is required for most professional occupations, as well as insight into any of the established disciplines of science and mathematics. Shayer and Adey also tell us that "nearly seventy per cent (70%) of human beings seem not to develop a capacity which they have been born to" (p. 137). This is a sobering thought for science teachers and curriculum writers.

According to Piaget, most students in the elementary school are exclusively "concrete thinkers"; therefore, if a student is to learn the "official version" of science, he must have concrete objects, events, and situations to visualize and participate in (Piaget, 1972; Renner, et al., 1978). Additional research in this area has indicated that concrete operational thinkers are successful in dealing with exclusively concrete concepts, but formal operational thinkers can comprehend both concrete and formal concepts (Lawson & Renner, 1975).

The developmental learning theory, embodied in the Piagetian approach, is a useful model for understanding how children learn science (Renner, 1978). Many science concepts, such as *force*, *gravity*, *momentum*, and *acceleration*, find common usage in everyday conversation; yet research shows that these are abstract and subtle ideas rarely understood by even the advanced science student (McDermott, 1984). Presumably such ideas cannot be easily assimilated due to lack of cognitive operational skills (Lawson, 1979). It is for this reason that science educators who adhere to the developmental perspective object to the introduction of theoretical concepts before the student learners are developmentally ready (Herron, 1978; Lawson & Karplus, 1977; Renner, 1976).

A child's understanding of a particular science concept is determined by his/her level of intellectual development. Research has been done to determine those factors which contribute to the development of a child's comprehension of scientific principles. Kohlberg (1969), Piaget (1970), and Selman (1980), utilizing a structural development approach, were able to study the concepts and thought-processes which children of different ages bring to the classroom. Studies by Inhelder and Piaget (1969) indicate that there is a strong relationship between children's growth in science comprehension and their growth in logical-mathematical reasoning ability. Several recent studies indicate that the growth of a child's capacity for abstract logic underlies the conceptual changes observed in the domains of science and logical reasoning (Selman, Krupa, & Stone, 1982).

Research by Inhelder and Piaget (1969) demonstrated that basic to the physical constructs necessary to understand mechanical concepts are the concepts of *weight*, *mass*, *time*, and *volume*. The structural-development model has been very useful in developing specific behavioral patterns involving logical reasoning. This model relies heavily on the use of Piagetian logical operations (Champagne & Klopfer, 1982; Lawson & Renner, 1975; Shayer & Adey, 1983). Among the methods used to assess a child's level of logical reasoning, the "input interview" seems to be the most popular (Nussbaum, 1979; Nussbaum & Novak, 1976). The studies of Selman and others (1982) indicate a strong correlation between a child's ability to reason logically and mathematically and his/her ability to master certain science concepts. Their study also demonstrated that the correlation between logical reasoning ability and the comprehension of scientific concepts was stronger on the elementary level than it was on the secondary level (Selman, et al., 1982). This supports the idea that many secondary students have not acquired the level of formal operationalism needed to master the science concepts taught at that secondary level (Renner & Lawson, 1973; Shayer & Adey, 1983). The majority of science educators continue to favor the Piagetian model of intellectual development (Albert, 1979; Herron, 1978). However, some researchers have suggested that the interests of research in science education would best be served if we discarded Piaget's theory of intellectual development in favor of a model which considers previously learned concepts (Novak, 1977b).

The developmental model of learning holds that intellectual development progresses through self-regulated levels, making possible a series of ever increasing abstractions (Arons, 1976; Barnes, 1977; Erickson, 1979). Through maturation of mind and body higher levels of thought and expanded learning of abstract ideas and concepts are made possible (Lawson, 1979). Whether one agrees or disagrees with the developmental model of learning, it continues to serve as a powerful jumping-off point for further consideration of alternative theories (Piaget, 1970; Pope & Gilbert, 1983; Selman, et al., 1982; Walters

& Gilbert, 1983).

Hierarchical

Robert Gagné, a neobehaviorist, in *The Conditions of Learning* (1970) describes a model of learning endorsed by most American psychologists (Biehler, et al., 1982). In his book Gagné proposes eight progressivel complex types of learning. These include: (1) signal learning, which involves essentially a Pavlovian stimulus-involuntary response; (2) stimulus-response learning, which is a Skinnerian operant conditioning type of learning where actions are shaped by reinforcement; (3) chaining, which involves repetition of a previously learned response; (4) verbal association, involving the "coding connections" between old and new words leading to new concepts; (5) discrimination learning, which involves the widening of the range of responses to a given stimulus; (6) concept learning, which includes the classification of ideas or things into a class or category; (7) rule learning, which involves the combining of previously learned concepts to answer a variety of questions; (8) problem-solving, the highest form of learning, which requires the combining of concepts and chains of concepts in order to solve new problems. Gagné argued that advanced learning can occur only after the lower levels have been mastered (Gagné, 1970).

A necessary skill in the learning of science is the ability to form concepts which, according to Gagné (1970), require verbal associations. Other researchers working more recently in science education have also shown the importance of language and verbal associations to the learning of science concepts (Champagne, et al., 1980).

According to the developmental-learning theorists, Piaget and Bruner, only mature students are capable of formal operations and symbolic thinking (Bruner, 1971; Inhelder & Piaget, 1958). Gagné (1970), on the other hand, suggests that the reason older students are more capable of learning concepts is that they have a much larger repertory of verbal associations. The ability to comprehend concepts and to manipulate them is fundamental to science learning (Lawson, 1979); however, Gagné is warning us that we may be teaching principles and concepts before the student has mastered the verbal associations necessary for such concept building. This leads to a phenomenon seen all too often in the science classroom, mainly verbal "superficiality." Students are able to memorize equations or state concepts, on cue, whether spoken or written, to the satisfaction of the teacher; but in reality the students have no understanding of what they are talking about (Champagne, et al., 1983).

As with any learning theory, the hierarchical model has its limitations. Many view it as a rigid and dehumanizing description of "behavioral objectives" (Jones & Russell, 1979). Gagné (1968), however, did not intend the hierarchical model to replace the developmental model of Piaget but rather to complement it. Learning should be viewed as an important aspect of total development; however, the use of a hierarchy to explain human development does provide a useful perspective. One is able to explain the transfer of understanding from learned ideas to new problems. Jones and Russell (1979) suggest that such successful transfers may provide a hierarchical definition for a developmental stage like "concrete operational." They also suggest that this type of transfer across levels of learning verifies the cumulative nature of the hierarchical model rather than the additive nature of the developmental model.

Some educators view the hierarchical model of learning as merely another version of Bloom's taxonomy (1976); and, although their work does overlap, Gagné's ideas focus more on "how" the students learn whereas Bloom's work examines "what" the students learn and at what rate (Jones & Russell, 1979). A conclusion made by both Gagné and Bloom, resulting from their research, is that a lack of prerequisite skills rather than general intelligence affect the ability of students to learn (Bloom, 1976; Gagne, 1968).

This idea has very special importance in the teaching of science because concept learning is crucial to the understanding of scientific laws (Shayer & Adey, 1983). The understanding of these laws requires a student to relate one concept to another (Larkin, 1981). Gagne suggests that when these concepts become "chained" together the student learns a "rule" and as these "rules" become more complex they lead to further learning (Gagné, 1970). Since rules are verbal statements, the ability to verbalize them may exclude understanding. When a student can use these rules, which are based on concepts, in order to react to other concepts, then we see his/her grasp of the rules and their relationships to understanding concepts (Gagné, 1970; Shayer & Adey, 1983). Thornburg (1984) offers the following example: "'Water is a compound of H_2O' is a statement of a rule but it involves the concepts of '*chemical*,' '*elements*,' '*bonding*,' and '*compounding*.'" In order for the rule to be meaningful and useful the student must learn the concepts as well. Teachers all too often confuse mere verbalization with true conceptualization of the rules (Champagne & Klopfer, 1980). One can determine this by reviewing the concepts making up the rule and to teach those not held by the students and, second, by giving the students ample opportunity to test the functionality of the rule by applying it to new situations (Gagné, 1970). As concepts are learned and combined into rules the content of the material taught becomes more relevant to the student and learning is more likely to occur (Thornburg, 1984). Russell and Jones (1979) remind us that hierarchical learning does not insist on any predetermined sequence of instruction. Shulman (1970) states one can move either "up" or "down" on the hierarchical scale and still achieve the desired results. The one important assumption of this model is that there are necessary prerequisites to the mastery of all superordinate skills (Jones & Russell, 1979).

This model is of particular importance to science educators for it allows us to construct, review, and modify science instruction for learners at all levels with an eye to concept learning. It also shows us how previously learned ideas and skills affect new learning. The importance of prior knowledge to learning has inspired additional research in and study of several contemporary models which are considered in the following section. These include the information processing model and the reception learning model (Ausubel, 1963; Bransford, 1979; Mayer, 1975; Novak, 1977b).

Reception

According to Novak (1977b) the label "reception learning" has come to mean a variety of things to educators and learning theorists; however, two important models to emerge from this paradigm are the "meaningful learning" model advocated by Ausubel (1968) and the "generative learning" model by Wittrock (1978). Both models hold tremendous potential particularly for science educators because they emphasize the assimilation of new concepts into an already existing structure of previously learned concepts (Ausubel, 1968; Kelly, 1969; Novak, 1979).

The meaningful learning model advocated by Ausubel (1968) views cognitive structure as a hierarchical set of concepts (subsumers) to which new information can be associated during meaningful learning. Ring and Novak (1971) in a study at Cornell University demonstrated, when no relevant subsumers are available for association of new information, rote learning takes place, at least temporarily, until some new relevant concept is formed. Albert (1979) contends that Ausubel views conceptualization as caused by external forces. In this respect Ausubel's theory is reminiscent of the behavioristic view according to which concepts exist in the external world detached from the learner but coming to him as an outside influence and are mastered through cognitive structures invented by man (Ausubel, 1968). Albert (1979) criticizes Ausubel's position of ignoring internal modes of thinking, and therefore, ignoring the internal dynamics of the very cognitive structure that acquire and maintain concepts. However, Albert contends this consideration of cognitive structures forms the cornerstone of Piagetian developmental theory. Novak (1981), on the other hand, insists that Ausubel's experience-dependent model better explains individual differences in performances with pendulum problems of different age groups at the formal operational level.

Another important characteristic of Ausubel's (1968) meaningful reception model is its description of "advance organizers" and their role in the facilitation of meaningful learning. Ausubel defines the advance organizer as introductory material which is presented ahead of the learning task itself. Its purpose, according to Ausubel, is to explain, integrate, and interrelate the material in the learning task with previously learned material. According to Weil and Joyce (1978), the most effective organizers are those that use concepts, terms, and propositions that are already familiar to the learner, as well as appropriate illustrations and analogies. The importance of these ideas to curriculum development is discussed in the section on science curriculum.

An important dimension of the reception learning paradigm is the generative learning model. This perspective on learning is of particular significance to science teachers for it acknowledges the importance of ideas which children bring with them to the science classroom (Osborne & Wittrock, 1983). Fensham (1980) stated that the teaching methodologies and curriculum development of the past 20 or 30 years were based on the premise that one need only to determine the knowledge deficiencies of students and to teach accordingly. Part of this position was to ignore the child's existing viewpoints and his/her language development dealing with scientific concepts. Osborne and Wittrock (1983) suggest we proceed on a comprehensive model of learning which requires full acknowledgement of the importance of what students bring with them to the classroom. The generative learning model (Wittrock, 1977) is consistent with such cognitive approaches to learning. According to Wittrock, the essence of this model is that the brain is not a passive consumer of information. Instead it selectively accepts or rejects information and subsequently constructs its own interpretations and consequently draws inferences from these interpretations.

It appears that a student will develop a new physical construct, including a restructuring of an existing construct, when the new information appears plausible, intelligible, and useful. It is this information which will be incorporated into long-term memory (Hewson, 1981; Osborne & Wittrock, 1983).

The research of Osborne and Wittrock (1983) indicates that the Generative Learning model has serious implications for teaching science. The specific areas addressed in their study include motivation, attention, information processing, generative learning, restructuring, problem solving, and curriculum.

A student's naive knowledge concerning his universe is only slightly altered even after considerable exposure to structured teaching (McCloskey, 1983; McDermott, 1984; Osborne & Wittrock, 1983). When and how these preconceived notions originate and develop are essential in the learning strategy. The generative learning model emphasizes, in terms of instructional strategies, the importance of memories, knowledge, and experience which the students bring as preconceived knowledge to the learning situation. Consequently, the learner becomes an active participant in the learning process. Linden and Wittrock (1981) insist that "good" teaching requires us to know the level and status of these preconceived views and their meaning to the students, then to pattern instruction so as to build upon the existing structure, and hopefully to modify the inaccuracies in the existing world. Osborne and Wittrock (1983) suggest this can be accomplished if we remain generally sensitive to and supportive of students' preconceived views and the reasoning processes which brought them to these views.

Science was thought to proceed from the simple and concrete to the abstract and formal, much like Piaget's levels of intellectual development. It was, therefore, logical to assume the science teacher need only wait for the students to reach the appropriate level of cognitive development and teach accordingly. However, current research indicates the level of cognitive ability does not necessarily preclude the learning of science concepts. Also the presentation of science concepts to the students in the classroom has very little influence on their preconceived views of the world.

Summary

For the purposes of this study, three general models of learning were examined. These included the Piagetian model of development; the hierarchical model of Gagné, and the reception model advanced by Ausubel and Kelly. These models were not intended to be exclusive but rather representative of the concerns and issues relevant to science education.

The developmental model of Piaget continues to be useful to the science educator because one can observe the growth in cognitive abilities and a corresponding ability to grasp the formal and abstract concepts so important to the learning of science. The hierarchical model of learning advanced by Gagné has also been a powerful force in shaping science curricula. According to Jones and Russell (1979), the greatest strengths of this model include "defined learning outcomes" and the "appropriate sequencing of instruction." According to Gagné, hierarchies are intended to allow each student to advance at his/her own pace and pathway. The bright learner, according to Gagné, will utilize past learning or innate abilities to skip over certain prerequisites. Consequently, preconceived knowledge may be used to achieve higher-order cognitive skills, such as problem-solving (Gagné, 1970). This model continues to be useful because it allows for learning regardless of the sequencing selected and, therefore, respects the differences in levels of preconceived knowledge (Jones & Russell, 1979).

The reception learning model also acknowledges the importance of preconceived knowledge. A major position taken by Ausubel (1963) is that each learner holds idiosyncratic concepts learned from experiences in the environment and derived from concepts currently held in society. While Ausubel's theory does not meet with general acceptance among science educators, it does offer a useful alternative for consideration of the "cognitive structures" vs. "cognitive operations" issues. Piagetian theory suggests that children learn by developing general cognitive operations (Barnes, 1977; Renner & Lawson, 1979). Novak (1977) believes that children learn by developing a hierarchical framework of orgnaized concepts, and central to this model is the emphasis on the student's existing construct of knowledge about the world. Further research is required to determine whether formal cognitive operations are possible even without prior knowledge of the content (Lawson & Renner, 1974). The following sections examine how science learning interfaces with preconceived knowledge.

Preconceptions and Science Learning

Preconceived Knowledge and Instruction

There is a growing body of research which indicates that for teacher-student interaction to be effective it is critical for the teacher to understand the student's status of preconceived knowledge (Champagne et al., 1980; Erickson, 1979; Kelly, 1969; Osborne & Gilbert, 1980). In spite of the fact that formalized science appears logical, neat, and totally coherent to casual observers, this may, in fact, not be the case. The affective dimension of science and the personal nature of theorizing and formulation of theory can be illogical (Einstein & Infeld, 1938; Koestler, 1976). This statement suggests that even scientists integrate their affective identity with cognitive factors in attempting to make sense of their experiences (Head & Sutton, 1981). Why then should we not expect the same personal and affective approach to making sense of the physical universe on the part of children (Champagne, et al., 1983)?

Some specific studies have attempted to measure the level of preconceived concepts in science on the part of elementary and secondary students (Osborne & Gilbert, 1980; Watts, 1983). Watts referred to these preconceived viewpoints as "alternative frameworks," rather than dismissing their notions as "wrong" or "misconceived." In spite of the fact that many of these "preconceived" concepts may be totally contradictory or mutually exclusive, they nevertheless cause little or no conflict to the students who hold them (Watts, 1983). The research indicates that the student's view of his/her physical world is clearly and demonstrably at odds with scientists' views (Champagne, et al., 1983; McCloskey, 1983; Pope & Gilbert, 1983). In order for a student to accept the "scientist's view," he/she must be presented with experiences and problems which create a cognitive dissonance resulting in the substitution of the scientist's view for his/her own view as the more intelligible, plausible, and fruitful explanation. This is the process by which an exchange of conceptual views takes place (Champagne, et al., 1980; Hewson, 1980).

Naive knowledge of physical concepts held by students of all ages affects the degree to which students are able to accept the "official science" viewpoint (Pope & Gilbert, 1983). Research has shown that naive "alternative frameworks," used by students to interpret classroom experiences and the resulting explanations may be different from or in total conflict with what the teacher expected (Nussbaum & Novick, 1980).

A method of determining the strength of the naively held preconception is to encourage the students to think about a single procedure involving a proposed investigation and then to predict an outcome using their own view of physical constructs (Osborne, 1981). This method may include group discussions, metaphors, and analogies which link with the real world of the student. This engenders the active, deep level and committed cognitive processing necessary for students to master scientific concepts and to decide to accept or reject the "official science" viewpoints (Champagne, et al., 1982; Nussbaum & Novick, 1980; Pope & Gilbert, 1983).

It seems from the research that this type of teaching, while not traditional, is necessary for the students to gain a sense of personal involvement with scientific concepts (Pope & Gilbert, 1983). If students are to exchange their preconceived notions about their physical world for the scientist's view, these open-ended approaches are necessary (Minstrell, 1984). Merely telling a student the correct view, couched in scientific jargon, is ineffectual (Driver, 1973). Preconceived ideas usually form the basis for the child's view of his physical world (Hewson, 1980). A student faced with new explanations or concepts will not incorporate them into his/her own constructs without good reason, particularly if such an act must be at the expense of the existing views (McCloskey, 1983). These preconceived ideas usually form the basis for the child's view of his physical world (Hewson, 1980).

The process by which students can transform or reject their personally held concepts of the physical world and accept the more "official" scientific view is crucial to this entire question. The processes for modifying preconceived constructs (schema) are just being understood (Greeno, 1980). Recent studies have identified two general processes for schema modification. First, modification of schema occurs when one or more variables become fixed, resulting in a less abstract schema. Second, modification occurs in a schema when a fixed portion is replaced by a variable resulting in a more abstract schema which becomes more plausible in the mind of the student (Greeno, 1980; Rumelhart & Ortony, 1977).

While Rumelhart and Ortony (1977) suggest a gradual modification of schema, other theorists indicate a more dramatic and spontaneous shift to a new paradigm (Kuhn, 1962). These dramatic shifts in paradigms seem to require some dialectical processes, such as the Socratic method of teaching as suggested by Renner and Lawson (1973) or individually prescribed lessons as suggested by Champagne and others (1983) and Minstrell (1984).

Summary. There is evidence that thinking processes of both children and adults are dialectical; it is this idea that constitutes "the transformational key" in cognitive development (Riegel, 1973). The dialectical issue is further addressed in the section on language and preconceived knowledge.

Another idea which surfaces in the literature is that schema modification is maximized when a student senses a difficulty or contradiction with his presently held concept and comes to realize that this difficulty or contradiction can be resolved with a different schema (Anderson, Spiro, & Montage, 1977). There is very little difference of opinion in the literature as to the existence of preconceived knowledge of mechanical concepts or the importance of this knowledge to learning science. That there can be a great difference in content between the student-held view and the "official view" is also well documented (Champagne, et al., 1983; Renner & Lawson, 1973). The controversy arises when reasons for the confusion between views are discussed (Cohen, Hillman, & Agne, 1978; Driver & Easley, 1978). The following section will examine the persistence of the preconceived views and the ways they hamper a student's ability to learn science.

Persistence of Preconceived Views

According to Piaget (1964), a child must first act upon his world as he sees it. Then he rearranges it, transforms it, and modifies it to form his own view of the world. Through experiences the child forms preconceived concepts used to explain the experience.

Preconceived views which result from personal interactions with the world influence all future learning. If it happens that these views are fundamentally incorrect, the effect on learning is likely to be negative (Champagne, et al., 1980; McCloskey, 1983). Newton's Laws, the accepted version for understanding motion, are a neat and scientific set of empirical statements; however, one must remember that these ideas developed and evolved over many centuries of thinking about motion. Newton said his discoveries concerning the motion of objects came not by sudden insight but rather by continually thinking very long and hard about them until he had worked them out (Newton, 1686).

A student should not be expected to accept, without question or confusion, a model which appears to be more unreasonable than his own. The acceptance may come if it is integrated into the total educational process and cognitive development of the child (Einstein & Infeld, 1938; Piaget, 1970). Research indicates that these self-constructed views of the world become firmly entrenched in the intellectual and cognitive repertory of the child and are not easily modified (Champagne, et al., 1980; McCloskey, 1983). Of all our interactions with the physical world, our experiences with the motion of objects is by far the most common. These experiences occur daily in our life whether at work or at play and, more importantly, whether we are aware of them or not. It would seem reasonable to expect that students, as a result of these common experiences, would hold a fairly accurate view of the laws of mechanics. The literature does not support this contention (McDermott, 1984).

Preconceived ideas are difficult to dispel and students utilize these misconceptions as a basis for justify-ing new course material (Champagne, et al., 1980). This work has interesting ramifications on the elementary level where the amount of formal instruction in science is minimal (Champagne, Klopfer, & Gunstone, 1982). Students accept new information and distort and misinterpret it in order to fit within their framework of naive preconceptions (McCloskey, 1983; Minstrell, 1982).

A study carried out by McCloskey, Kaiser, and Proffitt (1984) examined students' understanding of simple motion and the ways their ideas changed with age. Children between the ages of 4-12 years were shown a model train traveling on an oval track on a table three feet above the floor. A steel ball was positioned on a flat car behind the engine. The children were asked to predict where the ball would strike the floor as the car turned the curve. The children made their prediction by placing a cup where they thought the ball would fall. The children were also asked to predict how a ball would emerge from a circular clear plastic tube, open at one end, which ran alongside the train track on top of the table. The ball was made to move in the plastic tube at the same speed as the train. Again the children were asked to place a cup on the floor where they expected the ball to strike the floor. The younger children (4 to 5 year olds) predicted that in both cases the ball would fall straight down. More than 50% of the children (5th and 6th grades) knew that the ball rolling from the plastic tube across the table moves forward as it falls to the floor. However, they had more difficulty in projecting this reasoning to the example of the ball rolling from the flatcar as it rounded the curve. In this example only 25% of the older children knew that the ball dropped from the train would also move forward as it fell. The researchers suggest this increased difficulty in determining how a ball falls from a moving train is caused, in part, by a visual illusion. The train's motion provides a moving frame of reference which complicates the perception.

The results imply that the youngest children in the study were as accurate in their predictions as were the college students. Thirty-five percent of the preschoolers and kindergarten students predicted incorrectly, compared to 73% of the third and fourth grades, 59% of fifth and sixth grades, and 40% of college students. It is suggested that this is due to similar stages of language development in children (McCloskey, et al., 1984).

A study by Minstrell (1982) indicates that preconceived notions persist in spite of instruction. One reason for this persistence, suggests Minstrell, is that most of our present curricula and teaching strategies ignore these preconceived constructs held by students. Working with 55 high school physics students over a 2-year period, Minstrell found that, even though these students had strong mathematics and science backgrounds, their preconceived notions about mechanical questions were fundamentally at odds with their conventional objectives.

Initially, a preinstructional quiz was given to all students to determine the extent to which alternative explanations were used to answer fundamental questions concerning motion. The answers were categorized into correct and incorrect sets and examined to see what conceptions were being utilized and whether they meshed with the formalized system of physical ideas.

One of the problems used was a demonstration developed by Trowbridge and McDermott (1981) called "The Speed Comparison Test." The students were asked to observe two balls rolling along two separate tracks. The tracks were designed so that one ball continued to accelerate and the other accelerated part of the time and then was allowed to slow down. The students were asked questions like: "Were the two balls ever moving at the same speed and how could they know that?" Minstrell (1982) found that 30% of his high school age population were clearly confused as to the distinction between speed and distance; another 20% demonstrated some difficulty in conceptualizing their answers. Their responses were either vague or ambiguous. The remaining 50% of the students were able to distinguish between speed and distance, and their justifications were reasonably correct and logical. Some of the logical arguments used were appropriate for only one particular position of both balls but would be inappropriate in another speed position context. Of those students who answered correctly, there were still some who confused "same position: with "same speed."

McDermott (1983) working with university students found similar reactions. In her study, 30% of the introductory physics students confused "same position" with "same speed." Minstrell collected his data in a classroom setting, and McDermott collected her data in a clinical interview setting; yet their results were similar.

Studies dealing with college students in introductory physics courses reveal that at this level conceptual difficulties dealing with physical phenomena persist (Trowbridge & McDermott, 1981). The researchers looked at students in physics classes which ranged from remedial physics courses to calculus-based advanced physics courses. One interesting finding relevant to the present study is that preconceived notions concerning the students' physical world was causing learning difficulties even at the college level (Trowbridge & McDermott, 1981).

There are some studies cited in the literature which indicate that science teaching does change the views and concepts held by the child (Osborne & Cosgrove, 1982). In many cases, however, these changes are different from what is desired (Bell, 1981; Champagne, et al., 1983). Examples can be found where older students hold concepts which are less consistent with the scientifically accepted model than those held by younger students (Osborne, 1981; Osborne & Cosgrove, 1982; Osborne & Wittrock, 1983).

This phenomenon of the child's view of his physical world regressing before improving is not unique to science and is found in other learning studies (Strauss, 1981). The evidence indicates that a child's preconceived knowledge of his physical world plays a strong role in the manner in which he can assimilate the teacher's view of the physical world and incorporate it into his own (Osborne & Wittrock, 1983). In some cases the student would unintentionally and unknowingly misinterpreted those concepts taught in the classroom so that the new information would not be in conflict with their preconceived view of the world (Freyberg & Osborne, 1981). A growing body of research continues to support the idea that students' preconceived views are both pervasive and persistent and that this knowledge tends to interfere with, rather than enhance, the learning of science (Brumby, 1982; Champagne, et al., 1983; Fleshner, 1963; Green, McCloskey, &

Caramazza, 1980; Viennot, 1979).

Summary. The major consequence of this growing body of research is that teachers and theorists should not view students as lacking in knowledge but rather as being in possession of a large and complex body of information built up from misconceptions and illusions gained from interactions and experience with the real world. Students have been shown to hold strong preconceptions concerning mechanical questions and use of problem-solving strategies that differ from those used by scientists (Clement, 1979; Champagne, et al., 1982; Larkin, McDermott, & Simon, 1980; McCloskey, et al., 1980). When a student's naive beliefs are not taken into consideration as part of educational strategies, instruction may only provide the student with new terminology for expressing his erroneous beliefs (McCloskey, et al., 1980).

Preconceptions need not be viewed exclusively as obstacles to learning. Clement (1982) found, by testing college students, the effect of preconceived knowledge can be used as a "zeroth-order model." The students' prevailing status of preconceived notions can be modified in order to achieve greater precision and generality. The results from several studies dealing with secondary and college physics students show that, when they are made aware of their preconceptions and are encouraged to contrast their views with the accepted scientific view, they are able to reconcile the differences between the models (Arons, 1976; Clement, 1982; Fuller, Karplus, & Lawson, 1977). The realization by science educators that these views exist in the minds of learners is essential for the development of learning and teaching strategies. According to Champagne and others (1980), one of the primary reasons for the numerous misconceptions held by students of all age groups is the misuse of language and confusion over scientific terms. The following section will examine the role of language in the formation of preconceived ideas concerning mechanical concepts.

Role of Language in Preconceptions

Piaget (1969) said that language does not constitute the source of logic but is, on the contrary, structured by it. Piaget had focused a long-standing interest in the role of language in the development of ideas. As early as the 17th century, René Descartes, in opposition to Locke's empiricism, maintained there are innate ideas that are not traceable to experience; however, Descartes' theory was pushed into relative obscurity with the development of behaviorism and associationism (Freedman, 1978).

Noam Chomsky (1968) renewed interest in the possibility of innate ideas. He maintained that all languages rest on the same basic principles, and the ways children in different countries learn to use their native tongue led him to postulate that these principles are innate. The behaviorist-associationist's explanation of language acquisition (Skinner, 1953) stresses the building of stimulus/response associations through imitation and reinforcement. Chomsky suggests language is based on invariant properties, or linguistic universals, that are genetically determined. Thus, he argues, the mind of the newborn child is not a blank slate.

Carol Chomsky (1969) made an interesting discovery that children confuse "ask" and "tell" during early elementary school. This is not because they do not know the meaning of these words but because in certain sentences the implied underlying structure is confusing to them. The confusion over the meaning of certain words is known as the "transformational grammar theory" which proposes a particular sequence in the development of the child's comprehension and production of grammatical sentences based on the emergence of rules of transformation. This theory has received increasing support from developmental psychologists because it obviously forms an important bridge between grammatical and semantic development. Robert Gagné (1970) describes the conception of learning endorsed by most American psychologists. In his book, The

Conditions of Learning (1970), Gagné emphasizes verbal associations as a crucial element of learning; furthermore, he argues that more advanced kinds of learning can take place only when a person has mastered a large variety of verbal associations.

N. Chomsky espouses the cognitive approach to psychology which emphasizes the role of thought in determining behavior. This cognitive approach is especially influential in American psychology at the moment (Freedman, 1978). Chomsky (1968) holds that the child must be exposed to language in order to develop it, but the child's inherent intellectual capacity is a prerequisite for this development.

When Chomsky and others talk about innate structures they are not referring to specific grammatical rules but rather to an intellectual capacity that is expressed in the form of language (Freedman, 1978). Concept-formation ability in a child improves with age; certain concepts that are difficult at one age become easier later. According to Freedman (1978), concept formation requires the abstracting of grammatical rules and depends on the complexity of the rule, also on the stage of development of the child and the number of experiences to which he has been exposed. It is possible that there are one or more critical periods in the acquisition of language. Slobin

(1971) suggests, as some proof for the critical periods of language acquisition, that some adults have much more difficulty learning a second language after childhood. Science utilizes a long and confusing list of terms. Consequently, one of the problems teachers encounter when trying to teach physical concepts is that many of the terms used in classical mechanics like _force_, _momentum_, _acceleration_, and _speed_ are also used in everyday life. This gives important terms ambiguous meanings and causes students to confuse lessons, experiences, and textbooks. Double meanings cause the students to interpret materials, lessons, and experiences in terms of common meanings rather than the way the instructor intended (Champagne, et al., 1983; McDermott, 1984).

Research by Bransford and McCarrell (1974) and Anderson and others (1977) indicate that a student's personal preconceptions dealing with subjects other than the physical sciences tend to facilitate his/her learning patterns. However, a student's preconceptions concerning the physical world are logically antagonistic to the "official" view and often persist even after exposure to science instruction (Champagne, et al., 1983; McCloskey, 1983). Champagne and her colleagues have suggested that correct usage of technical terms on the part of students can be facilitated by providing learners with ample opportunities for verbal interactions. This practice will help students become aware of those physical principles necessary to explain mechanical problems and the ways their views differ from those being taught (Champagne, et al., 1980, 1982, 1983).

A review of the literature dealing with science curricula on both the elementary and secondary levels indicates that a well designed model of physical concepts with the appropriate corresponding vocabulary presented in a professional manner was all that was believed to be required to meet the deficiency in the student's knowledge of his physical world. However, this method did not succeed in replacing the student's view of the world with the scientist's view (Champagne, et al., 1980; Fensham, 1980; Lawson & Renner, 1975). In order to address the problem of the role of language in student-held misconceptions of mechanical concepts, research is presently being conducted. In a paper published in 1979, Champagne, Klopfer, and Anderson reported on a study dealing with college students and their "belief systems." A surprising and unexpected result was evident: achievement results on the test used to directly measure physics knowledge Description/Observation/Evaluation = D.O.E.) was a poor predictor of success in learning mechanical principles. One might expect that the level of preinstructional or naive knowledge would usually be highly correlated with how much the students benefit from physics instruction. After a very careful analysis of the data collected from this study it was concluded that preconceived knowledge of physical principles is only one factor affecting the learning of classical mechanics but with a much weaker correlation than had been expected. It is assumed here that physics knowledge reflects a mastery of the conventional language and terminology one usually learns in a physics course (Johnson, 1964; Karplus, Lawson, Wollman, Appel, Bernoff, Howe, Rusch, & Sullivan, 1977).

Summary

Much of the research dealing with the quality of conceptual knowledge of basic mechanical principles reveals that most students have a poor grasp of the major concepts of Newtonian mechanics. However, this is not due to a lack of preconceived ideas or of science terminology. Students usually have a rich complex framework of interrelated ideas and vocabulary that form a system of "common sense" beliefs about motion (Champagne, et al., 1979). Some researchers have suggested that the students' perconceptions of the mechanical world and the scientists' official view are competing paradigms (Lawson & Renner, 1975; Shayer & Adey, 1983). More research will have to be

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done to establish the level of ambiguity concerning these competing paradigms: how students distinguish them and how the disparity in language usage and meaning affects the learning process.

The previous sections examined the importance of a child's preconceptions of his/her mechanical world and the resistance met by science teachers when attempts are made to change his/her views to the Newtonian view. Research indicates that preconceived views are developed through personal experiences with the physical world and that our science vocabulary is not adequate in influencing a child's view. Consequently, confusion with the language caused by its restrictive use in science concepts drives the student further from the official scientific model. Studies have shown that students feel comfortable with their views and feel no compelling need to alter them. Studies have also shown that students across all intellectual levels persist in their views and even the brightest of students tenaciously cling to false mechanical principles. The following section will examine the various levels of intellectual assessment with emphasis on the gifted student and the problems he/she encounters in the learning of science.

Levels of Intellectual Assessment in American Education

The present study focuses on the preconceptions dealing with certain mechanical concepts held by gifted students. Since "giftedness" represents a specific but arbitrary designation of intellectual ability, this section of the literature review will attempt to examine the wider spectrum of intellectual assessment in American education. The assessment of intellectual abilities and skills has occupied the interest of educators and theorists alike for many years.

Although intelligence has been recognized since the time of the Romans, it was not until this century that any attempt was made to measure it (Stanley, George, & Solano, 1977). Galton (1869) did the pioneering work in the mid-19th century with the intellectually gifted; however, he was unable to quantify the specific traits of intelligence which characterize the gifted. It was the genius of a French psychologist named Binet, in attempting to screen out the mentally retarded from the school system in Paris, who produced the first numerical scale for measuring intellectual development (Guilford, 1967). Binet's work stimulated interest among other researchers in the assessment of intellectual abilities. Terman (1925) seized upon Binet's original model and transformed the scale for use with all children, particularly in identifying the gifted.

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It was Terman who multiplied the decimal score of the Binet scale by 100 in order to arrive at the famous I.Q. score (Intelligence Quotient Score). While working at Stanford University in 1916, Terman refined and tested the Binet Scale; this work resulted in the Stanford-Binet instrument which has become synonymous with the measuring of intelligence.

The assessment of intellectual development continues to serve as a fertile area of educational research. The literature indicates that current research has changed our perspective and understanding of intellectual and cognitive development. A significant model for understanding intellectual development has been recently advanced by Guildford (1959). In order to provide a systematic and comprehensive basis for conceptualizing human intelligence, Guilford developed a "structure-of-intellect" (SOI) model. This factor-analytic model utilizes a three dimensional matrix which defines a cross-classification of intersecting categories of activities (Guilford, 1967).

Another area of research dealing with intellectual ability which has proved to be very useful is the longitudinal developmental-descriptive study. Various studies were initiated in the late 1950s and are still in progress (Stanley, et al., 1977). Significant work in this area was carried out by Torrance. After studying large numbers of individuals from diverse social, ethnic, and economic backgrounds, he has shown the I.Q. score is not necessarily the only predictor of gifted behavior (Torrance, 1960). According to Torrance (1973), the study of gifted and creative behavior is far more meaningful for educational purposes than the I.Q. score since it has little or no racial or socioeconomic bias and, therefore, provides a means of reaching children from all socioeconomic backgrounds.

The present study focuses on the level of preconceived knowledge of certain mechanical questions among gifted fourth and eleventh grades; however, it seems appropriate to examine other intellectual levels. Categorizing or labeling is always a dangerous business; this is particularly true in the case of human beings. There are too many subtle differences to be represented on a simple chart or numerical scale. Yet it becomes necessary to recognize these differences and set them in some type of hierarchical order so that an educational strategy can be implemented which suits the intellectual needs of the student.

historically, the terms used to delineate the different categories of intellectual ability have varied considerably (Liebert, Poulos, & Marmor, 1977). The consensus among professional agencies dealing specifically with retarded children has been that there are three global levels of retardation. Until recently, these three levels were moron, with an I.Q. range of 50-69; imbecile, with an I.Q. range of 25-49; and idiot, with an I.Q. range of 25 below. Presently the American Association on Mental Deficiency (AAMD) and the World Health Organization (WHO) have implemented the terms mild to replace moron; moderate to replace imbecile; and severe to replace idiot, although the I.Q. ranges have been unchanged (Liebert, et al., 1977).

The educational community has implemented labels which reflect the capabilities dealing with school work; here we find the educable mentally retarded (EMR), trainable mentally retarded (TMR), and custodial levels. Again the I.Q. ranges remain essentially unchanged (Thornburg, 1984).

The American Association on Mental Deficiency offers the following definition for mental retardation: "Mental retardation refers to significantly sub-average general intellectual functioning existing concurrently with deficits in adaptive behavior and manifested during the developmental period" (Thornburg, 1984). According to Thornburg (1984) and Teleford and Sawrey (1981), the definition of mental retardation is a descriptive term regarding the current status of the individual's adaptive behavior and functional level, irrespective of etiology or curability. Many misconceptions and prejudices surround mental retardation, and no medical or educational term has been defined in so many different ways and only recently have attitudes toward the mentally and physically handicapped begun to change (Biehler & Snowman, 1982).

Current research shows that low levels of cognitive development seem to require an assessment which involves the child's current repertory of educationally relevant preconceptions and intellectual skills. It is felt that this knowledge will make it easier to pattern an effective educational strategy and will facilitate educational planning (Teleford & Sawrey, 1981). It is interesting to note that assessment of low level cognitive abilities, particularly those studies done during the last decade, has shown that students who test very low may not actually be retarded but rather have fallen victim to culturally biased tests (Sternberg, 1982; Torrance, 1973).

Much of the current research dealing with learning patterns of the educable mentally retarded indicates the interest is in developmental patterns and adaptive behavior (Teleford & Sawrey, 1981). Studies by O'Brien (1978) and Weiss and Zieglar (1979) on the cognitive development of retarded versus non-retarded children have shown that all children pass through the same Piagetian stages of development and in the same order. However, the retarded children pass through the stages more slowly and attain lower levels of development compared to the non-retarded learner. This research indicates that the retarded learner is essentially equivalent to the non-retarded learner except for his/her slow rate and lower level of cognitive development (Teleford & Sawrey, 1981). These results can be reassuring to the teachers of the mentally retarded since it suggests that no special insights or conceptual framework is required for teaching. Education, in general, has much to learn from the studies of the mentally retarded. It is reasonably clear in the literature that science students, including those on the college level, have difficulty comprehending certain elementary ideas concerning motion (Clement, 1982; McCloskey, 1983; McDermott, 1984). Why, then, should we be surprised or disappointed when students, characterized as mentally retarded, struggle with such concepts? Teleford and Sawrey (1981) showed that mentally retarded students benefited greatly in their early stages of learning when they were provided with error-free experiences. They need prompt and systematic feedback and concrete evidence of their progress. Science by its very nature can provide a mechanism wherein the student can interact with his physical world at whatever cognitive level is appropriate. There can be little doubt that all learners whether "retarded" or "gifted" come to the classroom with an established, structured, and believable view of their physical experiences (Champagne, et al., 1980; McDermott, 1984).

For purposes of classification, an I.Q. of 69 or below is considered mentally retarded; an I.Q. between 70 and 129, the largest segment of the population, is designated as average; and an I.Q. of 130 and above has been designated, by most states, as gifted (Thornburg, 1984). As was mentioned earlier, any classification system has inherent shortcomings by considering some features of intelligence but ignoring others. However, since no system can be perfect, *any* system which is useful in meeting the intellectual and emotional needs of *most* of the students is worthwhile. Particularly important to this study is the level of intellectual and cognitive ability designated as "gifted." This term has both educational and legalistic implications. The following section of the review will focus on giftedness.

The Gifted Student

In the hierarchy of educationally-defined levels of intelligence, the upper end of the spectrum is called gifted. Concern for the identification and education of the gifted is not recent. Plato wanted to discover the most able youth so that they might be educated for state leadership and suggested tests for native ability for their selection (Alexander & Muia, 1980).

The scientific investigation of the gifted can be traced readily to Francis Galton's (1869) reports of his genetic and statistical studies of the gifted. He concluded that the principal elements contributing to achievement are "ability, zeal, and readiness to work." A number of "special aptitudes," each of limited scope, are also recognized. According to Galton, those of outstanding ability to achieve possess a greater quantity of these particular abilities. They possess the same qualities as do others, but they have them in greater quantity.

Much interest was aroused by these reports and by subsequent investigations of social influences on the gifted, as well as the role of genetic factors in giftedness (Cattell, 1915; Ward, 1906). Reports of leadership, mental health, and ability were made; and genius was presented as superior mental ability by L.M. Terman (1904, 1906).

Interest in the gifted in the 20th century has gone through three distinct periods. First, there was an emphasis, spearheaded by Lewis Terman, on identifying and describing the gifted. Second, a period ensued that largely consisted of the laying of groundwork by interested groups for special education and curriculum for the gifted; and finally the launching of Sputnik gave social and financial impetus to the provision of programs that would serve their needs (Thornburg, 1984).

The reports of Terman and others (1925) constitute an important landmark in the investigation of giftedness. He investigated more than a thousand gifted children and reported on their development and behavior. These children were studied well into adulthood, and these investigations have provided a large volume of data about giftedness (Oden, 1968; Terman & Oden, 1947, 1959). Investigations of the gifted have been numerous, and a substantial body of literature in this area has accumulated (Passow, 1979; Stanley, et al., 1977).

As with other categories or labels dealing with intellectual and cognitive levels, the need for a comprehensive and operational definition is essential. The national definition of giftedness proposed by the Council of Exceptional Children requires that students demonstrate "high intellectual, creative and academic abilities" and require services and activities "not ordinarily provided by the school" (Thornburg, 1984).

The literature on giftedness reveals a profusion of definitions; this is due in part to researchers using identical criteria in a variety of ways (Abraham, 1958).

Abraham (1958) reported that his graduate research assistant uncovered 113 different definitions for giftedness. However, Renzulli (1978), based on his research findings, defined giftedness as having three dimensions: first, a person must be above average in intelligence; however, he does not specify any particular cut-off score as measured by an I.Q. test; second, giftedness much involve clearly focused motivation; and third, creativity.

In spite of the divergent views in defining giftedness, there appears to be some general agreement in identifying those who are gifted. The most common instruments for identifying these students have been the I.Q. test and the test of creativity (Thornburg, 1984; Torrance, 1973). Recently the shortcomings of conventional intelligence tests and the I.Q. derived from their administration have been recognized; however, this has not greatly reduced the use of the I.Q. as a convenient frame of reference for thinking about the gifted. The research indicates that a high I.Q. is the most common method of identifying the gifted (Passow, 1979). Included among the gifted are those who achieve at exceptional levels in certain academic areas (Stanley, 1979).

The equating of giftedness with a high I.Q. is understandable in light of the research. Studies have shown that gifted students consistently score higher on standardized achievement tests than their classmates of average intellectual ability, when their ages are held constant (Terman, 1925). Yet Stanley (1979) showed that having an exceptionally high I.Q. does not include the possession of any special abilities. In a test conducted at Johns Hopkins, Stanley and his colleagues (1979) showed that less than 50% of a group of gifted students scored higher on a mathematics reasoning test than did students from a non-gifted program.

Since the 1960s several states have initiated subsidized programs for the gifted. Consequently, identification of gifted students has taken on additional meaning. Since the majority of states presently reimburse school districts at a higher rate depending on the number of students who meet the gifted criteria, schools have had to develop specific policies for testing and identification. For example, in Pennsylvania an I.Q. score of 130 or higher constitutes giftedness; reimbursement for State supported gifted programs are made on that basis (Pennsylvania Department of Education, 1978). California, on the other hand, uses an I.Q. of 140 as its cut-off line (Delisle & Renzulli, 1982). There is some evidence that schools are attempting to include in their testing programs a more subjective approach which may involve teacher, parent, and peer recommendations (Delisle & Renzulli, 1982). Attempts to identify the gifted with or without special reservations may also include, but are not limited to, the following:

Group Tests of Intelligence:

Rough devices to discover those individuals who are not achieving at a high level and those who are achieving at high levels and score low. Both warrant further investigation (Passow, 1979).

Individual Intelligence Tests:

Administered by a psychologist trained in intrepretation and use of scores. Special areas and abilities are identified in testing of individuals who do exceptionally well in certain areas such as mathematics or science (Stanley, 1979).

School Grades:

Employed as a rough generalization, it is safe to say that students who obtain a preponderance of A and B grades are more likely to be gifted than those who get lower grades. However, high grades are sometimes given to increase moral and motivation; and biases are bound to creep into the situation as a result of personality, as well as social and cultural factors involved in the complex schoolroom situation (Delisle & Renzulli, 1982).

Tests of Achievement:

Tests are employed systematically in the school; high scores above the norms for age and grade warrant further testing.

Teachers' Ratings:

Students with gifted potential may escape detection by the previously mentioned methods. In order to provide an additional opportunity for participation in a gifted program, teacher recommendations are important (Stanley, 1979). However, this method has recently come under criticism. Pegnato and Birch (1959) showed that teachers were unable to identify their gifted students.

Summary

Guilford (1959) stated that it is encumbent upon the educational community to classify the gifted and to design an instructional strategy which promotes their academic welfare. It appears from the literature that interest in gifted programs has in fact increased. In 1978-79, the combined fiscal support for the gifted educational programs in the United States was slightly over 68 million dollars. However, during fiscal year 1980-81, this support increased to over 126 million, three times the rate of inflation during the same time period (NSF Report, 1983). Thus, evidence would seem to indicate that there is a growing awareness of the need to provide those programs which will nurture the abilities and potentials of the intellectually talented.

This section of the literature review attempted to outline the different designations of intellectual ability. Since the focus of this study deals with preconceived knowledge among gifted students, this section of the review emphasized the intellectual characteristics unique to this group. Studies by Clement (1982) and Peters (1982) have shown that even honors physics students at the high school and college level have difficulty understanding fundamental mechanical concepts. Champagne and others (1980) and McDermott (1984) have shown these difficulties are tied to common misconceptions dealing with motion. An important vehicle available to science educators for the identification and consideration of preconceived knowledge is learning theory, particularly as the model relates to conceptualization. The following section examines those learning models which integrate both the role of intellectual development and preconceived knowledge in the learning of science.

Models of Learning: A Science Educator's Approach

This section considers those generalized models of learning theory as reviewed previously; however, the present focus is on the specific relationships of these various models to the learning of science, including the ways learning models relate to science education in its mission to test appropriate concepts to interactive learners. Larkin (1981) stated that science education has benefited greatly from recent progress made in cognitive learning theory.

The focus of all science learning from the youngest child to the most sophisticated post-graduate student is on the personal interacting with the physical world and the explaining of the natural phenomena which are observed. These explanations then form the basis of organized science curricula and teaching (Bass & Maddux, 1982). Thus, the initial interactions between a learner and his world form the basis for all future learning (Piaget, 1975). According to Inhelder (1972) the central theme of Piagetian cognitive learning theory is that there is an intimate relationship between what is to be known and the person seeking to know it; likewise, the theory holds for the constructivist model of cognition and memory advanced by cognitive psychologists (Brown, 1976; Piaget, 1971).

According to Renner and Lawson (1973) science educators need to be deeply concerned with the intellectual development and the building of physical constructs by their students. The learning of physical principles from the metric system to quantum mechanics requires the use of these constructs. The models which have proved to be most useful in understanding how students conceptualize their world include, but are not limited to, the learning hierarchies of Gagne (1970), the construct for "meaningful learning" submitted by Ausubel (1968), and the rich theory of "stage development" advanced by Piaget (1971).

Lochhead (1978), Champagne and others (1980) have investigated the integration of science education and cognitive psychology and have found that no one learning model, exclusive of all others, is adequate to explain the process of learning science. As stated above, the importance of preconceived knowledge to the learning of science and the way this knowledge impacts on the learning process is central to the learning hierarchies for intellectual skills advanced by Gagné (1968). Yet the positive transfer of information is not characteristic of all learning; and Gagné (1968) proposed that preconceived ideas or what he called "what the individual knows" does not necessarily have hierarchical organization. One of the more exciting curricular innovations which has resulted from the integrative approach to preconceived knowledge and the structure of that knowledge is the Concept Structuring Analysis Technique (ConSAT) (Champagne & Klopfer, 1980). Champagne (1980) and her colleagues admit that inspiration for this technique, which involves concept-relating and concept-fitting into larger constructs, resulted from the research of two cognitive psychologists, Paul Johnson (1964) and Richard Shavelson (1974).

Ausubel (1966) and Novak (1977b) have shown that the reception learning model also relies heavily on the role of preconceived knowledge. According to their view, meaningful learning can take place if previously learned concepts exist to which new information can be associated (Ausubel, 1968). This model is consistent with the activities naturally associated with science, namely participation and the processing of information. The student is considered an active and contributing partner in the learning process.

Human learning is a purposeful activity that varies in complexity; therefore, the greater the number of components, the more they must be interrelated if they are to have meaning for the learner. Complex behaviors are processes coherently in the mind so that they are useful to the learner now and in the future.

Information-processing models account for the range of variables affecting memory, learning, and retention (Bransford, 1979; Craik & Lockhart, 1972; Resnick & Glaser, 1976). According to Bransford (1979), as the learner responds, the stimuli are represented as auditory information or visual information, which temporarily registers on the senses. Some aspect of the sensory system must pay attention to the information or it will disappear (Gage & Berliner, 1984; Joyce, 1979). This model of memory is based on the idea that learning is stored in memory structures through internal operations that not only make storage more efficient but also make the information available for recall. Most explanations have a cognitive orientation because cognitive processing is essential to the information-processing model (Bransford, 1979; Mayer, 1975; Reese, 1976). The common view is that this cognition involves the complete processing of enormous amounts of information, both new and currently stored in the brain (Mayer, 1975). We receive and register stimuli or learning materials in the sensory storage and represent information through verbal, visual, or tactile modes (Bransford, 1979). Thus both conceptual and information-processing approaches to retention are more complete explanations of human memory than are association theories (Thornburg, 1984).

Perhaps the richest and most meaningful model of learning for the science educator is the developmental model with Piaget as its principal advocate (Renner & Lawson, 1973). In terms of what is observed in and out of the classroom, this approach seems to make the most sense (McCloskey, 1979). The understanding of science requires both concrete and abstract reasoning skills, depending on the level of sophistication of the concept. If one is going to merely look at whether an object will sink or float, this obviously is a concrete experience. However, if one is to explain the concept of floating vs. sinking, utilizing density and specific gravity, such explanation will require abstract and formal thinking (Piaget, 1974).

High school and college level physics teachers generally assume that the students have attained mastery in abstract reasoning and formal operationalism. This is evident in the materials and goals of the courses

(McCloskey, 1983). However, recent studies have shown that this may not be the case. Research was recently conducted on college physics students chosen randomly from introductory level college physics courses and tested for selected Piagetian tasks. SAT verbal and math scores were correlated with course grades and used as criteria for achievement. Studies showed that 58% of the population were concrete operational. The Piagetian level was weakly correlated with the level of course and course grade. On the other hand, the SAT scores were strongly correlated with the course level and course grade (Cohen, et al., 1978). It is evident from the literature that developmental levels of cognitive ability are diverse on the college level and that less than half the college subjects tested have reached the formal operational level (Arons, 1976; Chaipetta, 1976; Juraschek, 1974; Lawson & Renner, 1974). Studies by Lawson and others (1977) and Peters (1982) showed that even when students have acquired formal operationalism and have been identified as honors physics students, they also demonstrate difficulties with mechanical concepts.

Studies indicate formal operations can be taught if the students have the necessary maturation level and if they have successfully utilized concrete operations (DeCarcer, Gable, & Staver, 1978; Renner, et al., 1978).

A study by Lovell (1971) also showed that formal operational thought may be affected by certain attitudes, including familiarity and credibility. Attitudes are important because they influence the willingness on the part of the student to accept the results of his/her own experimentation or task analysis in the face of contradictory preconceptions (Quattrone & Courville, 1977). The learner's willingness to incorporate a new idea depends, to a large degree, on the status of his/her prevailing storehouse of physical constructs. Consequently, preconceived knowledge can interfere with, rather than enhance, learning.

There is a growing interest in how we can determine the level of preconceived knowledge held by students. One study which demonstrated this used college students who had to verbalize their thoughts and ideas in the "loud thinking" method. Students were forced to give explanations to support their view. In this way their misinterpretations and omissions of cognitive processes became evident (Clement, 1982; Minstrell, 1984). One factor contributing to a student's repertory of preconceived views is his/her understanding of terminology. Studies show that where students have a correct view of the physical concepts they also tend to use correct terminology, but understanding rarely comes as a result of correct use of terminology (Lochhead, 1979).

The traditional approach of teaching physics by transferring equations and facts from the teacher to the student has come under attack. Some researchers contend that this method relegates the student to a passive observer role (D'Amour, 1979). If the student's view of his/her physical world is to come into some agreement with the scientist's view, the student will need to prove or disprove his/her personal theories by his/her own efforts (D'Amour, 1979; Wales & Stager, 1978). According to Eanet (1981), students' only interest seems to be to memorize successfully those facts with which they are presented; consequently very little attention is given to understanding.

Summary

Science is much more than a collection of facts. Science education to be effective at any stage of development must involve teaching and learning strategies which emphasize understanding, rather than memorization.

This section of the literature review examined several learning models which emphasize those intellectual and cognitive skills relevant to science learning and, also, the ways these learning theories address the role of preconceived knowledge. Those researchers investigating the process of cognitive development speak of "good habit of mind." Learning theorists tell us that the cognitive process is not taught or given by the teacher; but rather students are assisted in developing their own knowledge system, incorporating it into their prevailing construct (Champagne, et al., 1983; Lin, 1979; Lochhead, 1979). Students of all ages come to the classroom with a vast accumulation of information which may be correct or incorrect; this preconceived information is of great consequence to their learning of science. Shayer and Adey (1983), Champagne et al. (1980), and Minstrell (1984) argue that the principal focus of every science lesson should be the discipline and knowledge structure, and not just isolated facts.

The relationship between the learning process and intellectual development among children continues to be of great interest to both researchers and theoreticians. This part of the literature review attempted to examine those models of learning and levels of intellectual development which impact on the learning of science. For purposes of the present study, special emphasis was placed on the intellectual designation of "gifted" and also the importance of preconceived knowledge to the models of learning considered in this review. These included the Developmental Learning Model of Piaget, the Hierarchical

Model of Gagné, and the Reception Model of Ausubel and Kelly.

The recent proliferation of commission reports criticizing the current state of science education will undoubtedly refocus the attention of the nation on science instruction in the schools. The solution to these concerns will require the continued integration of all learning theories and processes in order to provide a full and comprehensive analysis of the situation. The research examined in this section indicates that cognitive processes change drastically during the school years of a child and the cognitive abilities available to a student also vary during this time (Inhelder & Piaget, 1958).

While most of the research in learning theory has been stimulated by Piagetian developmental theory, the work of Gagné (1963) and Ausubel (1963) have contributed useful and meaningful perspectives. Current research on preconceived knowledge of physical concepts and its influences on learning science have contributed to an expanding model of learning and cognitive development (Champagne, et al., 1983; McCloskey, 1983; McDermott, 1984).

Research on learning theory and cognitive development influences the science curriculum. In the 1950s, science instruction was largely textbook-bound and considered relatively unimportant on the elementary level (Karplus &

Thier, 1978). By the early 1970s, following the avalanche of new curricular programs of the 1960s, there was a general reduction in the amount of content and less reliance on the text. The purpose was to allow more in-depth treatment of concepts, more "hands-on" experiences, and better content organization. During this period Helgeson (1978) suggested that the current status of science materials began to emerge. These included concerns such as "pollution, natural resources, and energy," to name a few. Also according to Helgeson (1978), the *process*, *concepts*, and *attitudes* toward science became important in the curriculum.

Some researchers have indicated regretably that the last 2 or 3 years have seen a return to reliance on the textbook, factual content, and fewer laboratory experiences (McCloskey, 1983; McDermott, 1984; Minstrell, 1984). In the high schools, science courses are seen as difficult and accessible only to the intellectually elite (NSF, 1982); however, research by those examining preconceived knowledge has shown that students of all intellectual levels have difficulty with some physical concepts because of preconceptions based on personal experiences (Champagne, et al., 1980; McCloskey, 1983; McDermott, 1994; Peters, 1982).

The following section of the literature will review and examine the history of science curriculum reform in the United States, particularly those programs which resulted from efforts of the National Science Foundation, including the effectiveness of these science curricular reforms in terms of student interest, reconciliation of student-held views with the Newtonian model, and the learning of science concepts at all levels of intellectual development.

Science Education: A Study in Continuous Curricular Reform

Historical Overview

Reforms on the Secondary Level

Following the Second World War, the demands of an expanding electronic and technological economy fully taxed our scientific manpower. Concurrent with the economy, the rate of development of science-based knowledge was accelerating at a rapid pace. Because of these external pressures, very little attention was being paid to science curricula and textbooks. The shortage of scientific expertise available to education coupled with an increase in general student enrollment, from 25 million in 1950 to 35 million in 1960, placed science education in a role of diminishing priority (National Science Foundation [NSF] Report, 1980).

In 1957, the bubble burst. The Russians launched

Sputnik I into orbit and the space race was on. The public perceived the American educational system in second place, an intolerable position for the wealthiest and most highly technological nation on earth. Consequently science education in this country came under serious attack from all directions. Thus was born the National Education Defense Act of 1958 (NEDA) and a flood of unprecedented dollars earmarked for educational projects. The initial efforts were made on the secondary level in order to produce immediate results, or that was the intended purpose. As a result, curricular reforms of physics, chemistry and biology curricula were undertaken.

The Physical Science Study Committee (PSSC, 1960) was the first reform project to get underway on a large scale, and it set the tone for those to follow. Funding began in 1956, and an early decision was to start afresh rather than to repair the existing model of high-school physics. By 1960 the first commercial version of the PSSC text was completed and made available. Much traditional content was omitted to make room for in-depth treatment of modern topics physicists felt most accurately represented their discipline. Two central ideas of physics, the wave-particle duality and the modern concept of the atom, served as the foci for sequencing. Stress was placed on fostering the attitude that physics is an inquiry activity to be pursued for its own sake and on developing an understanding of the structure of modern physics. Clearly the PSSC was designed to be intellectually demanding and to appeal to no more than the upper 25% of the twelfth-grade population (those who typically elected the subject in 1960). However, studies from 1970-1980 showed that less than 20% of the students taking high school physics actually elected the PSSC course (NSF, 1982). A reason given for the less than spectacular success of the PSSC curricula was the lack of adequate junior-high-school preparation in science.

One group of physicists and science educators, known then as the Harvard Project Physics group (HPP), called attention to the narrow appeal of PSSC and set out to correct that problem with a high-school physics course of their own. They cited the drop in the percentage of twelfth-graders electing physics since the advent of PSSC as evidence of need. The first commercial version of their efforts appeared in 1970 under the shortened title, Project Physics. This course was designed to depict physics as a human endeavor within a cultural context. Considerable attention was devoted to the historical development of several important ideas of physics; also a philosophical view of the discipline was included (Project Physics, 1970).

Yet another response to the continuing decline in enrollments in the physical sciences was forthcoming in 1971. The work of the Engineering Concepts Curriculum Project (ECCP) culminated in the publication, The Man-Made World. Thus, the focus here was on developing technological literacy among future citizens destined to live in the age of technology (NSF Report, 1980).

Soon chemists were hard at work on two curriculum projects which differed significantly from existing secondary school courses and from each other. The Chemical Education Materials Study (CHEM) writers developed the text, Chemistry: An Experimental Science, published in 1963. The target population was eleventh graders (the upper 40%) who typically enrolled in a college preparatory chemistry course. Emphasis was placed on the predictive and explanatory value of thought models in modern chemistry. In contrast, the Chemical Bond Approach (CBA) group did not produce its own film series, but rather cross-referenced its topics to both selected CHEM study and PSSC films. Like CHEM, this alternative approach reacted against existing courses which presented a reactants and products view of chemistry. As the name suggests, CBA stressed the central role of the chemical bond (NSF Report, 1980).

Meanwhile biologists had developed three alternative approaches to tenth-grade biology. All became commercially available in 1963. The Biological Science Curriculum Study (BSCS) yellow version text, Biological Science: An Inquiry into Life, emphasized the cellular developmental view. The BSCS green version test, High School Biology, presented the ecological/evolutionary view and employed Ausubelian advance organizers. The third option, known as BSCS blue version, stressed the molecular/biochemical approach. Although the treatment differed markedly within topics, all three versions showed a 70% overlap of topics and employed the same unifying themes (Glass, 1961).

Although the earth scientists had started work on a source book for teachers in 1959, they did not begin work on a curriculum project until 1962. Thus is was not until 1967 that the Earth Science Curriculum Project (ESCP) had a course ready for commercial publication. The approach was to stress the unity of the subdisciplines of astronomy, geology, soil science, and physical geography and to incorporate relevant concepts from biology, chemistry, mathematics, and physics as needed (NFS Report, 1982).

At about this time, junior-high-school science began to share some of the spotlight. Too many students in the newly developed high-school courses (BSCS, CBA, CHEM, and PSSC) were having trouble. It was asserted that a major source of the trouble was that students entering these courses lacked both basic science skills and an understanding of the meaning of science (NSF Report, 1982). Consequently, two courses designed to correct these intellectual ills were devised as suitable for either eighth or ninth grade. Introductory Physical Science (IPS) was published in 1967. It emphasized the roles of operational definitions, thought models, laboratory skills, and inquiry training (Smith, 1969). Just as IPS was designed to form a basis for the high-school physical science curricula, Interaction of Matter and Energy (IMP) was supposed to prepare students for BSCS biology (Smith, 1969). Published commercially in 1968, this junior-high-school physical science course was also inquiry oriented. The content emphasized scientific processes, interactions (chemical and physical), and energy flow in both nonliving and living systems.

ECCP and HPP, which were mentioned earlier, were indeed quite different and both stood in marked contrast to the earlier PSSC. So, too, did the Intermediate Science Curriculum Project (ISCP) differ greatly from any previous project. ISCP emerged in 1971 as an integrated 3-year series of courses designed primarily for use in grades 7, 8, and 9. These courses were comprised almost entirely of guided discovery laboratory exercises that were to be self-paced for the most part. The overall purpose was to serve the general education function of junior-high-school science by developing scientific literacy, rather than to develop skills and understandings particularly needed in BSCS, CBA, CHEM, or PSSC high school courses (Hurd, 1970).

An important factor in the curriculum reform movement initiated in the 1960s was the programs for updating teacher education. Title III funds allocated under the Elementary and Secondary Education Act (ESEA) and the National Defense Education Act (NDEA) supported many inservice programs. Commercial book publishers also conducted some inservice programs (Welch, 1979); however, the largest single source of support for teacher education came from the National Science Foundation Institute Programs. According to Helgeson (1974), the Academic Year Institute (AYI), Summer Institutes (SI), and the Cooperative College School Programs (CCSP) were prominent factors in the updating of the backgrounds of science teachers during the 1960s. The impact of the Institutes was widespread. Schlessinger (1973) reported that over 50% of all secondary school science teachers in their national sample had attended one or more NSF Institutes. Yet, according to Helgeson (1974), many science instructors teaching during their study had not attended any institutes. During the 1970s, with reduced funding from federal and state sources, inservice science education declined. The record on the elementary level was worse. Stake and Easley (1978) found that 14% of the elementary teachers attended an NSF Institute. Studies by Welch (1977) showed that inservice needs of elementary and secondary teachers vary, but the most common purpose reported was to aid teachers in dealing with students from minority groups with related special needs of a particular course being taught. A study conducted by the National Science Board as reported in "Science Education for the 1980's," found that over 90% of the elementary and secondary teachers included in the study felt they needed to learn more about recent advances in science and 75% felt they needed to improve their understanding of basic science concepts.

A comprehensive study conducted by Welch (1977), involving 344 teachers and 167 principals from a 12-state region, demonstrated that science teachers and principals agree the most important factor in improving science education is the preparation and training of instructors. Welch further concluded that the goals of science education can best be achieved by providing time, support, and facilities to the teachers.

The National Science Board in their report, "Educating Americans for the 21st Century" (1983), stated that the most obvious and immediate problem in science education today is the quality and style of elementary and secondary teaching. The report further stated that a substantial number of the nation's 1.17 million elementary teachers lack sufficient knowledge, training, and interest to teach science effectively. The Board also stated that the Nation's 100,000 secondary teachers also required additional training in science and cognitive psychology because of the rapid development of new scientific and technological knowledge.

The National Science Board concluded that the state and local efforts to improve the situation were critical. However, it also concluded that the Federal government has a compelling interest in this problem and must play a primary role in providing teacher training. The Board made a series of specific recommendations for upgrading science teachers and for establishing higher standards for new teachers (NSF, 1983).

Summary. Although the impact of these courses has been less than spectacular, as evidenced by the current decline in enrollment and interest in secondary science (Nation at Risk Report, 1983), they did pave the way for bringing together the theoretical models for learning that the conceptual knowledge scientists felt were important for students to master. Recently the factor of preconceived knowledge has been introduced into the equation for curricular reform. Consequently science curricula continue to be revised and reformed (Champagne, et al., 1983; McDermott, 1984; Minstrell, 1984). Logically, the success of any secondary science program should be underpinned by the quality and effectiveness of the elementary science program. The following section examined the development of the elementary science programs over the last 20 years.

Reforms on the Elementary Level

> Children in first grade are natural scientists . . . then something happens. Questions that seem interesting to a child, that are real scientific questions, get perfunctory and discouraging responses instead of serious answers they deserve. People have been taught that they are too dumb to understand science.
>
> Carl Sagan, 1982

The roots of elementary science education can be traced back to the 1850s with the introduction of the "Pestalozzian Object-Teaching" movement. A version of this method is best represented by the "Oswego Method" developed at Oswego, New York (Lammers, 1955). The 1870s saw an emphasis placed on elementary science education because of the rising importance of science and technology brought on by the industrialization of America. Herbert Spencer in this essay, "What Knowledge is of Most Worth," underlines this movement toward a practical application of science (Ozman et al., 1981).

By the end of the 19th century the National Education

Association's Committee of Ten issued an extensive report which emphasized laboratory and direct experiences for both elementary and secondary science programs (Kuslan & Stone, 1969). By the 1920s a shift from a purely experiential dogma to a conceptual one had taken place. Men like Pierce, James, and Dewey were having tremendous impact on science education (Kuslan & Stone, 1969).

The essence of this movement was that the methodology of science is more important than the mere accumulation of knowledge (Dewey, 1916). The importance of science in the elementary grades, during this period, is evidenced by the interest shown by various educational groups. In 1947, the National Society for the Study of Education devoted its entire 45th Yearbook to problems of Science Education. This was again the case in 1960 when the Society dedicated the entire 59th Yearbook to the problems of science education, particularly elementary science.

By the 1960s the full impact of Sputnik was already felt in the elementary sciences. It was only a matter of a year to 2 after the introduction of the high school programs before the Elementary Science Study (E.S.S.) course was introduced into the elementary schools. This was a process-oriented course emphasizing the central processes of science (Kuslan & Stone, 1969).

By the 1960s the concern for elementary science teaching reached its zenith. The American Association for the Advancement of Science (AAAS) initiated nationwide feasibility studies to determine what must be done and what methods were to be used in carrying out these studies. During the years 1960-1963, conferences were held across the country involving scientists, teachers, administrators, psychologists, and science education specialists. One of the recommendations was that the concepts and methods of inquiry used in science should be taught to children in ways that are consistent with the meanings and spirit of modern science (Hurd & Gallagher, 1968). A massive nationwide assault on the prevailing science curricula was coordinated by a Commission on Science Instruction appointed by the AAAS.

One of the first programs resulting from this effort was a sequential (K-6) program called: Science--A Process Approach (SAPA). It was supported by the American Association for the Advancement of Science and the National Science Foundation. It was developed between 1963 and 1965 (Hurd & Gallagher, 1968). The distinguishing characteristic of this program was its objective to teach process rather than content (Kuslan & Stone, 1968). The teaching of the process skills included the basic skills in grades (K-3) and the integrated skills taught in grades (4-6). The basic skills included observing, communicating in science, classifying, measuring, using numbers, space/time relations, prediction and inference. The more highly integrated process skills included: formulating hypotheses, making operational definitions, controlling and manipulating variables, interpreting data, and experimenting (Livermore, 1964). The sequencing of process skill developments was an integral part of the curriculum design. This idea was based on the Gagne model of learning: these process skills are hierarchical, and in order for the higher integrated skills to be mastered a student must first develop the lower basic skills (Gagné, 1963).

A revised SAPA II offers a less rigid, modularized structure of SAPA I. A year's work consists of 15 modules grouped into clusters according to similarities in process and content. Program designers state that certain "key clusters" of SAPA II contain materials for developing important process skills and should receive high priority. Teachers are expected to use their judgment in choosing the sequence of the remaining clusters. No textbook exists for the SAPA Programs; however, the teacher is provided with guides, a set of behavioral objectives, a sequencing chart showing how the skills are interrelated, and assorted evaluative materials and tests.

In 1961 the Science Curriculum Improvement Study (SCIS) was developed at the University of California, Berkeley, under the direction of Robert Karplus. The SCIS elementary program contained a series of "units," some of which are not closely related to each other except as they all incorporate a "guided discovery" methodology (Karplus, 1974).

A few basic concepts of science were chosen which were felt to be widely useful and applicable; the program was structured around them. These concepts were chosen from the physical and life sciences. The life-science track included the concepts: *organisms*, *life cycles*, *populations*, *environments*, *communities*, and *ecosystems*. The physical science track included the concepts: *material objects*, *interactions and systems*, *subsystems and variables*, *relative positions and motion*, *energy sources*, and *electric and magnetic interactions*. In order to provide some introductory readiness activities at the kindergarten level, a unit called *Beginnings* was added.

The general strategy of the SCIS Program is based on the Piagetian model of development to conform to the preoperational, concrete and formal operational stages. The SCIS Program deals with abstractions on three levels. The concepts of *matter*, *living things*, *variations*, and *conservation of matter* are first-level abstractions. Second-level abstractions include *interactions*, *cause-and-effect relationships*, and *spatial relationships*. Third-level abstractions include *energy*, *equilibrium*, *steady state*, and *living things*. The early units include many activities which require concrete operations. The later units are designed to encourage formal and abstract reasoning. A goal of the program is to provide the students with exercises facilitating the transition from one stage to the next (SCIS Sourcebook, 1968).

SCIS is essentially a laboratory course; however, the students are not expected to discover all the concepts for themselves. The teacher, acting as an organizer, helps "invent" certain ideas such as "magnetic field," in order to assist the students in their discovery process.

In 1963 an important contribution to elementary science curricula was made by Educational Services Incorporated. The program was called Elementary Science Study (ESS) and emphasized the importance of exploration time for students. The importance of unstructured periods for exploration as a condition for learning has been supported by Hunt (1961) and Bruner (1956). An important aspect of ESS is that children will have an opportunity, as Hawkins (1965) puts it, "to mess about in science."

The ESS provided teachers with a wide range of science materials from which units could be selected to provide a varied assortment of exercises and experiments. The materials were designed to be inexpensive and to allow for students to work alone. The basic premise of ESS was that the student is responsible for learning; through personal experiences with science, he/she will develop useful learning skills and conceptual knowledge (Duckworth, 1974).

The three elementary programs examined in this review by no means exhaust the list of curricular reforms instituted in the 1960s; however, they are representative of the programs which resulted from the massive expenditures made during this period. The following section will examine the effect of these programs on science education.

The Effect of the New Curricula Upon School Science

From 1965 to 1975 over a billion dollars per year was expended under the Elementary and Secondary Education Act of 1965 (E.S.E.A.), most of it going into more than 500 new curricular projects on the elementary and secondary levels, including program development, implementation and the purchase of materials (Welch, 1979).

In spite of these huge expenditures, there is little evidence to indicate that the new curricula were successful in increasing interest in science (National Academy of Science, 1982). The percentage of students actually taking science in grades 9-12 fell from 60% in 1960-61 to 48% in 1976-77 (Welch, 1979). However, the trend in the elementary grades hopefully seemed to be in the direction of increased interest (National Science Board, 1983). In 1961-62, 100 minutes/week were devoted to teaching science in grades 4-6. In 1976-77, this increased to 175 minutes/week. This trend is encouraging, but Welch (1979) concludes that curriculum does not seem to have much impact on student learning no matter what curriculum variations are used. The recently published report, "A Nation At Risk" (1983), by the National Commission on Excellence in Education, appointed by President Reagan, pointed out that the high school and college students involved in their study were elementary students during the 1970s, the period of unprecedented expenditures of time, effort, and money for developing and implementing elementary science curricular projects. The report further pointed out that "over half the population of gifted students in this country do not match their tested ability with comparable achievement in school." Furthermore, the study cited, "College board achievement tests reveal a constant decline in recent years in all subject areas but the greatest decline has been in physics scores." It was also reported that there was a steady decline of science achievement scores of America's 17-year-olds as measured by national assessments of science tests administered in 1969, 1973, and 1977. A major conclusion of the Commission was that this measurable decline in educational performance on the part of children particularly in science and mathematics was due to, in large part, the "disturbing inadequacy of the educational process" and the resulting decline in interest in science.

A disturbing aspect of this problem of decreasing interest in science is that elementary teachers lack the confidence necessary to stimulate student interest. A survey of elementary teachers (K-6) in the State of Kansas found only 9% who felt qualified in science compared with 45% who felt qualified in English, reading, and history (Horn & James, 1978). Since less than 50% of the students in this country take science beyond the tenth grade (Welch, 1979), it follows then that the elementary sciences should receive higher priority on the national education agenda.

The National Academies of Science and Engineering (1982) have indicated that in 1981 the first and second grade students in the United States received an average of 1 1/2 hours of science per week. At the end of third grade, one-half of all students in the study felt they would prefer not to take any more science; by the end of the eighth grade, only one-fifth of all students questioned had a positive attitude toward science. In spite of the curriculum reforms previously mentioned, interest in science on all levels continues to wane.

Summary

This section of the literature review examined those curricular reforms instituted in the early 1960s that resulted, in large part, from the post-Sputnik reactions of the Federal government. The curricular projects described in this section have come under criticism for ignoring the practical applications of science by emphasizing pure science and appealing to only the brightest students. Sarah Klein, President of the National Science Teachers Association testified before the United States Senate Appropriations Committee on May 24, 1982. She stated that many of the criticism leveled at the NSF-supported curricula were justified. Klein further stated that the difficulty-level of the "new curricula" contributed to the large reduction in the number of students studying science at all levels. A study of Welch (1979) revealed that in 1976-77, 48% of all public school students in grades 9-12 were enrolled in at least one science class; however, during 1960-61, over 60% of the same group were enrolled in at least one science class. Enrollment figures for students taking chemistry and physics decreased even further. Using 1977 figures, it was demonstrated that the enrollment in high school chemistry and physics accounted for only 6.9% and 3.1% respectively of total secondary science enrollments (NSF Report, 1983).

In spite of the "scandalous" situation in science education, as Carl Sagan (1982) characterizes it, there are indications that the "new curricula" have brought some improvements. In a recent study by Shymansky (1982), 105 studies performed between 1960 and 1970 were analyzed involving 45,000 students. Shymansky compared students enrolled in the "new curricula" with those in the more traditional curricula. Each measure, which included achievement, attitude, and process skills, students taking the new NSF curricula scored overall 14% higher. Those students taking BSCS Biology and CHEM Study Chemistry scored 17% higher overall. An interesting finding from Shymansky's study is that students from low socioeconomic groups at all grade levels scored 24% higher using the new NSF-supported curricula than traditional curricula.

Sarah Klein (1982) in her testimony before the U.S. Senate felt that few teachers are left in the schools now who are qualified to teach the new curricula and the materials are badly in need of revision and modification in order to incorporate the changes which have occurred in the past 10 years, such as the use of computers in the classroom. Those who have studied the present state of science education unanimously agree that the problems on both the elementary and secondary levels are immense, diverse and complicated and, according to Klein, must be addressed on the national and local levels. This effect may be assisted by current research in cognitive psychology and learning theory. Studies dealing with the role of preconceived knowledge in the learning of science have provided science teachers with a learning model which acknowledges the personally held views of the students. The following section will consider a model for curriculum reform which integrates the role of preconceived knowledge in the learning process.

Global Summary

The Use of Preconceived Knowledge of Mechanical Concepts in an Integrated Approach to Curriculum Reform

A purpose of this study is to examine preconceived knowledge of certain mechanical concepts among gifted elementary and secondary students. In order to provide a broad theoretical background for the study, the literature review focuses on three general areas. They are: (1) a historical review of mechanistic models of our world from the Aristotelian to the Newtonian views and the ways these views influence our perceptions of the world; (2) a review of the research on learning theory and intellectual development as they relate to the learning of science; (3) a review of the research on preconceived knowledge of mechanical concepts as they relate to the teaching and learning of science. This section of the literature review will examine the research which justifies the use of an integrative approach to curriculum reform. An approach which integrated those issues is discussed herein.

The discipline of science is constructed upon a foundation of fundamental mechanical principles resulting from the Newtonian perspective on motion (Whitehead, 1968). Consequently, the comprehension of mechanical concepts and their reconciliation with a child's perception of the mechanical world are fundamental to the conceptualization required in learning about nature. The nature of motion may appear to be obvious, however, the subtleties concerning motion have intrigued thinkers from the earliest times (Holton, 1973). The ancient philosophers appreciated the complexities and subtleties of mechanical phenomena. The motion of the planets and the stars was considered the grandest of all natural mysteries and confounded men for centuries (Russell, 1945). Attempts to explain celestial motion served as the driving force for scientific inquiry for over 2,000 years.

Current research by McCloskey (1983), Champagne et al. (1983), Minstrell (1984), and McDermott (1984) have shown that students hold a view of their world which more closely resembles the "Aristotelian" and "impetus" models, rather than the official scientific "Newtonian" view. The studies indicate that students from diverse populations continue to be confused and confounded when attempting to explain simple motion; also, they tenaciously cling to the "Aristotelian" views which persist in spite of formal instruction in Newtonian mechanics.

While the research and interest in preconceived knowledge of mechanical concepts among students is relatively recent (McDermott, 1984), several great scientists recognized the problem many years ago. Einstein, writing in 1938, observed that the understanding of nature required conceptual and experiential components. Einstein felt the connections between concepts were logical; however, in order to "make sense" of these concepts, they had to be related to experiences. According to Einstein and Infeld (1938), the connections between concept and experience were not of themselves logical but rather intuitive; and the only distinction between empty fantasy and scientific truth was the degree to which these connections were made. Other scientists during the early part of this century spoke of this "intuitive insight." Scientists, such as Marie Curie, Neils Bohr, Hideki Yukawa and Werner Heisenberg to name a few, have all experienced this phenomenon of "making sense" from what had previously been incoherent or confusing (Holton, 1973).

Current studies indicate that students have similar difficulties in reconciling their concept of the physical world with the official and accepted version (McCl[illegible]y, 1983; McDermott, 1984). According to researchers, the difficulty that students experience in accepting the textbook version for explaining their physical world is that the textbook version does not justify their personal experiences (Champagne, et al., 1980; McCloskey, et al., 1980; Trowbridge, et al., 1981). According to Whitehead (1968) physical concepts are free creations of the human mind and are not uniquely determined by the external world. Yet formal education tends to stress the memorization of physical concepts and the appropriate language with emphasis on how the concepts interrelate. The connections between the concepts and experiences are not logical to the child and are, therefore, rarely understood (Einstein & Inheld, 1938; McDermott, 1984; Minstrell, 1984). Consequently, a discussion of the concepts alone rarely leads to understanding of the physical world. Einstein (1938) felt that it was only through the abridgement of personal experiences and concept that the correct conceptualization and, thereby, appreciation of the physical world were possible.

Studies by McCloskey (1983), Champagne et al. (1983), and McDermott (1984) showed that students from diverse populations have difficulty with reconciling their preconceived views of the world, based on personal experiences, with models presented in the classroom. The research further demonstrated that these diversely held views are basically similar, essentially incorrect, extremely persistent, and almost always hinder the learning process. As was mentioned previously, the student-held preconceptions tend to be Aristotelian in nature sometimes combined with the Medieval "impetus" view. It seems reasonable that students hold this view in light of the fact that the Aristotelian view of motion dominated European thinking for over 2,000 years and continues to offer a logical and reasonable justification for motion (McCloskey, 1983). According to the Aristotelian view of motion, a body will move only when it is moved or otherwise will come to rest. The students' experiences with the world involve the acts of pushing, pulling, and lifting. These experiences act only to reinforce a child's perception that all motion requires some type of pushing or pulling. The research shows that student-held views are rarely considered by the teacher; instead science education at all grade levels stresses the memorizing of concepts and processes based on current learning theory (Minstrell, 1984; Renner, 1978). This methodology has had little effect on the preconceived views held by students and has offered them no reason to abandon their views in favor of those being taught in the classroom and written in the texts. Consequently, students emerge from their science lessons without a functional comprehension of the most fundamental physical concepts; in most cases, the students are more confused after they have taken the course than they were before. It has become reasonably clear that the learning difficulties caused by preconceived views of physical ideas are consistent and similar across all populations and, therefore, hold important implications for science instruction (Champagne, et al., 1983; McCloskey, 1983; McDermott, 1984).

Previous attempts to reform the science curricula have been built around expanding skills and literacy or developing processes such as scientific inquiry (Karplus, 1981). The techniques used to achieve these reforms were based on the best prevailing learning theories and models of cognitive development. These goals and procedures are valuable and useful to the science educator and must be retained and updated. However, the research shows that in spite of our best efforts at curricular reform, students who are demonstrated formal and abstract thinkers persist in clinging to their pre-Newtonian views. The purpose of this section of the literature review is to examine that research which would suggest an approach to science curriculur reform which integrated the knowledge of preconceived views held by students with the more traditional research involving learning theory and cognitive developmental psychology.

The current research dealing with preconceived knowledge of physical concepts has its roots in educational research done in the early part of this century. In 1915 the great psychologist, Charles H. Judd, recognized the abstruseness of science as it is taught in the schools and suggested that the instructional rationale is to add to the student's accumulation of facts. Although Judd recognized the problem, he could not prescribe an effective solution because he possessed no basis on which to evaluate the probability of instructional effectiveness. According to Champagne, Klopfer, and Gunstone (1982), the situation is different today for empirical and theoretical research in cognitive psychology make possible the construction of theoretical models on which predictions can be based. They further suggest that an understanding of how students perceive their physical world provides a model for designing an instructional strategy for science students which can be expected to produce desired changes in the students. The work of learning theorists, such as Piaget, helped to launch the present interest in how students learn.

Piaget in 1929 and 1930 first published the results of his research on a child's comprehension of physical causality, an essential ingredient in science-learning and conceptualization. Piaget said that a student must "act" upon the world to "know" it. The current research indicates that children will "act" upon their world and will consequently construct a model for understanding it. This model may or may not be in agreement with what is being taught in the classroom. A recent study, utilizing Piagetian developmental theory, has shown that the development of physical causality is essential to the learning of science (Good, 1977). However, according to Wolfinger (1982), no study has been done to determine how a child's concept of physical causality is affected by classroom instruction. This research is important to those studying preconceived knowledge of mechanical concepts since Piaget stated that a child's interpretation of the physical world is based in part on his/her concept of physical causality (Piaget, 1930). The Piagetian theory of developmental learning continues to be a rich and useful model for science educators.

Current studies by Champagne and others (1980) have shown that some difficulties students encounter with learning physical concepts are caused by confusion over the meaning of scientific terms. Gagné (1963) said that the learning of concepts requires verbal association. Consequently, the Hierarchical Learning Model of Gagné is also important to those studying how children learn science. Some researchers have characterized Gagne's hierarchical learning model as rigid and dehumanizing (Jones & Russell, 1979); however, Gagne (1968) intended his approach to learning, not as a replacement for Piagetian developmental theory but rather as a complement to it. The hierarchical model of learning is somewhat useful to those studying preconceived knowledge since it aids in explaining how students transfer understanding from learned concepts to new problems (Shayer & Adey, 1983).

A third model for examining the process involved in learning is the Reception Theory. This model contains the "meaningful learning" paradigm advocated by Ausubel (1968) and the "generative learning" model advanced by Wittrock (1978). Both approaches hold tremendous potential for those studying the role of preconceived knowledge in the learning of science for they emphasize the assimilation of new concepts and new skills into an already existing structure of previously learned concepts (Ausubel, 1968; Kelly, 1969; Novak, 1979). Ausubel (1968) and Piaget (1974) stated that students have well established perceptions of their physical world which enable them to make sense of their observations; however, these perceptions are rarely consistent with those held by scientists. Ausubel (1968) was aware of the importance of preconceived knowledge to learning and made it a focal point of the reception learning model.

There is a growing body of research which suppports the contention of the learning theorists previously discussed that preconceived knowledge is an essential consideration for the development of a learning strategy and also must be integrated into the curriculum design. A comprehensive review of research studies dealing with preconceived knowledge of mechanical concepts prepared by McDermott (1984) cites several examples of science curricula changes on the secondary level resulting from these new insights. Studies by Clement (1982), Lochhead (1983) and Minstrell (1984) involve the use of students' preconceptions of mechanical concepts in the teaching and learning process. Students are allowed to interact with each other, to share their views and to compare them for similarities and differences. This "interactive dialogue" forces the student to articulate his/her views concerning mechanical questions and to compare them with the Newtonian view. Yet another study which emphasizes the level of preconceived knowledge involves a method known as Concept Structuring Analysis Technique (ConSAT) (Champagne & Klopfer, 1980). This technique is used to elicit a graphical representation of a student's cognitive structure and to measure the level of conceptualization based on the presently held views of the student as they relate to certain scientific concepts. According to McDermott's review (1984) of the state of the research on preconceived knowledge in mechanics, the studies are primarily descriptive and focused on specific areas (i.e., mechanics) rather than on methodology. However, McDermott further contends that physicists, psychologists, and science educators through a systematic investigation of the difficulties students encounter in learning physics have provided a new resource for improving instruction. Current research of preconceived knowledge has intersected with the larger issues of concept formation (McDermott, 1984), scientific reasoning (Fuller, et al., 1977), problem-solving (Larkin, 1981), and intellectual development (Piaget, 1970).

The relationship between intellectual development, specifically of the gifted, and preconceived knowledge is a principal concern of the present study. A purpose of the study is possibly to expand the model of giftedness to include student-held views of certain mechanical concepts. Several researchers suggest that an analysis of a child's preconceived views of the physical world may be more relevant to effective learning than other traditional criteria; i.e., IQ and creativity, SAT tests and grades (Renner, 1976; Renzulli, 1978). Ludlow and Woodrum (1982) stated that, contrary to conventional wisdom, the "gifted" student does not necessarily exhibit more advanced cognitive abilities, such as problem-solving, than does the "non-gifted" student. Sternberg (1981) examining "entrenched-concepts" and "non-entrenched-concepts" held by students, showed that concepts held by students were not a function of achievement or conventional assessment instruments. As a result, Sternberg (1981-1982) suggested we expand our notion of intelligence and giftedness to include a student's ability to learn based on his/her "non-entrenched" concepts; also it was felt that such student-performance could distinguish the "gifted" students from the rest of the population. This suggests that student-held views concerning certain concepts may play an important role, not only in helping to design an instructional strategy but also in evaluating the student's cognitive development (Sternberg, 1982).

It is evident in the literature that the basis for designing teaching strategies and curricular designs has relied heavily on the theoretical and experimental work of the learning theorists and cognitive psychologists. Yet, national studies show that student interest in science continues to decline. A report of the National Science Foundation (1982) states that only one-third of the schools in the USA require more than 1 year of science for graduation. In 1980 only 10% of the students who graduated from high school had physics. Other studies show that schools are the single largest cause of students losing interest in science (NSF, 1982); however, according to Carl Sagan, the public interest in science is intense. He offers as evidence the tremendous popularity of such programs as "Nova," "Life on Earth," "The Body in Question," and "Cosmos." As Sagan has also observed, the increasing popularity of science museums, science magazines, and science programs on T.V. "further testifies to an unsatisfied hunger for science and our intuitive understanding of its power and joy" (Sagan, 1982, p. 22).

According to learning theorists working in science education such as Champagne (1982), McCloskey (1983), and McDermott (1984), very little was understood of the way children learn science. Through intensive research dealing with problems students encounter in learning science which result from their preconceptions, a new consensus on the nature of learning is emerging. It is becoming evident that students who do well in formal science courses and demonstrate skill in solving textbook problems are not able to use this knowledge in interpreting actual physical events. According to Laureen Resnick (1983), this observation has been made with the most gifted of students on all grade levels and among honors students in our most prestigious universities. Resnick further suggests that the information gained about the ways students build and use their preconceptions in understanding the world must be translated into more effective instructional strategies. The research shows that students will construct meaning from experiences even when the information is incomplete. Consequently, the formation of structional preconceptions is inevitable (Ausubel, Novak, & Hanesian, 1978; L. Resnick, 1983). The confrontation of these preconceptions is the new challenge for science educators. According to a report of the National Academies of Science and Engineering (1982), the emphasis on formulae and scientific abstractions are introduced to students at too early an age and more emphasis should be placed on the qualitative aspects of science. Also the report suggests that it may be best to start science education at an early age, before the preconceptions become entrenched. The report, however, is careful to caution that a total retreat from computational skills and abstract thinking is not desirable and, in fact, may be counterproductive; however, it must be shown that the processes and statements of science can make sense and can be utilized by the students in understanding their world. Minstrell (1984), working with high school physics students and junior high school science students, has demonstrated that with patience and understanding a child's view of the world can be changed. He feels that teachers should take the time to learn what ideas the students have on various scientific concepts, how the students come to have such ideas, and then use their ideas as part of the teaching process. There should be more emphasis on ideas and processes of physics and less on the memorization of facts or the manipulation of mathematical formulae.

This dissertation began with a quotation by the great physicist and humanist, Victor Weisskopf. He said, "Nature is simple, but subtle" (Weisskopf, 1983). Einstein, the greatest physicist of this century, made a similar statement in 1938. He said, "Motion may be simple, but definitely not obvious." From the Aristotelian Age came the scholastic adage, "Who knows not motion, knows not nature." The ancients, not unlike Weisskopf and Einstein, also appreciated the fundamental yet complex nature of the mechanical world. It would seem that great thinkers across the span of human history have contemplated the subtle and elusive explanation for "simple" motion. If science education is to be successful, it must reach beyond the equations, vocabulary, and definitions to the subtleties of motion upon which students construct their perceptions of the world. It is clear in the literature that, if science education and curriculum development ignore the personally held views each student has of his/her world, then we will continue to fail in changing those views. Consequently, we fail to impart those subtleties of motion which form the foundation of a true and valid understanding of our experiences in the world. The intuitiveness that is spoken of through the ages of science theory is being rejected by the students; this rejection has caused a great loss in knowledge and appreciation of the physical laws which rule the mechanical universe.

Chapter 3

METHODOLOGY

The role of preconceived knowledge in the learning of science is currently receiving a great deal of attention from educational researchers. The University of Washington group led by Lillian McDermott, the University of Pittsburgh group led by Audrey Champagne and Leopold Klopfer, the group at Johns Hopkins University under Michael McCloskey, and John Lochhead and John Clement at the University of Massachusetts have demonstrated leadership in this area and are responsible for the bulk of current publications dealing with preconceived knowledge and science learning.

A careful review of the relevant literature was included in Chapter 2 of this study; it revealed that certain common traits relating to preconceived knowledge held by students were discovered by the researchers. For purposes of refocusing on the problem, these common traits are as follows:

1. Students of all ages have descriptive and explanatory systems for personal experiences which develop prior to any formal study of science.

2. These systems utilized to understand experience differ significantly from those taught in the classroom.

3. These preconceived views dealing with the physical world show remarkable consistency across diverse populations of age, ability, training, nationality, and sex.

4. These preconceived views are pervasive and resistant to change in spite of intense instructional intervention.

5. The preconceived views held by students dealing with certain mechanical concepts are rarely consistent with the Newtonian view of the world but rather consistent with an Aristolelian or Medieval impetus view. (Champagne, et al., 1980; Clement, 1982; McCloskey, 1983; McDermott, 1984; Viennot, 1979)

The presistence of these student-held views has far reaching consequences for science teachers for it demonstrates that traditional instructional strategies have failed to facilitate an appropriate reconciliation of preconceived knowledge with the lessons taught. According to Ausubel, Novak, and Hanesian (1978), this reconciliation is necessary for learning to occur. It is incumbent on researchers to investigate the levels of preconceived knowledge among learners at all stages of educational and intellectual development. The major focus of this study was to examine preconceived knowledge among gifted students in elementary and secondary levels.

Hypotheses Restated

The problem statement is "translated" into the following null hypotheses:

H1. There is no significant difference in the levels of preconceived knowledge concerning certain mechanical concepts between gifted and non-gifted students.

H2. There is no significant difference in the levels of preconceived knowledge concerning certain mechanical concepts between formal and pre-formal thinkers.

Selection of Site

The site chosen to conduct this study was the Wyoming Valley West School District situated on the west side of the Susquehanna River in central Luzerne County. Nine municipalities comprise the school district which serves approximately 6,000 students of a predominately white middle-class population. There were several reasons for selecting this school district: (1) there is a full-time gifted program (grades 1-6) which has been in continuous operation since 1969; (2) the district employs an administrator who assumes responsibility for supervision of the gifted program; (3) a completely detailed record of all aspects of the gifted program is kept individually in the files of the school psychologist; and, (4) there was willingness on the part of the administration and the classroom teachers to participate in this study.

Selection of Students

The fourth grade was chosen as one sample population for they, according to the literature, represent probable concrete thinkers (Shayer & Adey, 1983). Piaget and his collaborators showed that concrete operational thought is characteristic of childred in the 7- to 12-year-old age bracker (Inhelder & Piaget, 1958). However, to further establish the presence of concrete operationalism among fourth graders, a Piagetian test was administered individually to the fourth-grade students, and only those students who demonstrated concrete operationalism were included in the study. The fourth grade population consisted of a group of gifted and a group of non-gifted students. The 29 gifted fourth graders used in the present study represented the entire population of gifted students of the fourth grade level. The gifted students are relocated from their neighborhood schools and are self-contained in one building. These gifted fourth graders represent two class sections each having their own teacher. The non-gifted sample of fourth graders were chosen from another building in the district which housed 120 non-gifted fourth graders. Because the sample of 24 non-gifted fourth graders were chosen from one building, they represented only one geographic area of the district and approximately 7% of the total fourth grade population in the district. However, the elementary principals, guidance counselors and teachers assisted in selecting the non-gifted sample of fourth graders to match the socioeconomic background of the gifted sample.

In order to compare the levels of preconceived knowledge in two diverse age groups, a sample of eleventh grade students were also given the Preconceived Knowledge Test. In order to assure the eleventh grade samples of gifted and non-gifted students achieved the level of formal operationalism, a Piagetian test was administered. Consequently only those students who were successful on the Piagetian test for formal operationalism were included in the present study.

The importance of formal thinking to the understanding of science has been well documented (Champagne & Klopfer, 1982; Renner & Lawson, 1973; Shayer & Adey, 1983). The literature supports the notion that eleventh graders demonstrate formal operationalism in areas essential to science and mathematics (Renner & Lawson, 1973; Shayer & Adey, 1983). This grade level was chosen also because the members of both the gifted and non-gifted samples were taking the same physics course with one teacher. The eleventh graders chosen included 25 students who had been identified as gifted students by the site district when they had entered the first grade and 24 students who were identified as non-gifted by the site district when they entered first grade. The eleventh-grade students included in the study represented 13% of the total eleventh grade population of the school district and also represented a geographic cross section of the site school district. Because the total number of students available in the two groups was relatively small, no effort was made to balance the number of females and males. All the students in the study were enrolled in the school during the full academic year, 1983-1984, the time frame of this study.

Pilot Study

The test used to evaluate the level of preconceived knowledge concerning certain mechanical concepts was derived from several previous studies by Viennot (1979), McCloskey et al. (1980b), Champagne et al. (1980), Clement (1982), and Minstrell (1984). These were described in the section on the Preconceived Knowledge Test. Since previous studies had shown that incorrect views were common across all age groups (Champagne, et al., 1983b), it was decided to use the same instrument for the fourth and eleventh grades.

Since the use of the same instrument for this diverse age group was important to the study, it was necessary to choose questions and tasks which were understood by both age groups. To select a suitable set of exercises, a pilot study was conducted with 30 randomly chosen eleventh graders and 30 randomly chosen fourth graders from a neighboring school district. Approximately 20 questions and problems taken from several current studies were used in the pilot study. Only those 14 questions and tasks which students from both groups indicated they understood were chosen for inclusion in the Preconceived Knowledge Test. The protocol used in this pilot study for determining which questions were understood by both fourth and eleventh graders was the clinical interview method similar to that employed by Piaget in 1929 and more recently by Champagne (1980), Clement (1982), and Minstrell (1984) in their studies on preconceived knowledge. Each of the randomly selected students was individually questioned about his/her answers and then asked to justify them. From the interview it was determined whether the questions were understandable to both age groups. In the case of the fourth graders the classroom teachers, who observed the interviews, were asked to help determine whether their students demonstrated understanding of the question by the tenor of the clinical interviews and responses of their students.

Description of Testing Procedure and Instruments

The method used to examine and analyze the concrete reasoning ability of the fourth grade subjects included the clinical interview method (Trojcak, 1979). Each student was individually confronted with a series of questions and exercises dealing with physical phenomena to which they were asked to justify their responses. The Piagetian Test for Concrete Operationalism was administered and evaluated by this researcher and three Wilkes College senior psychology majors. The four testers received limited training by a Wilkes College professor, an expert in psychological testing and evaluation. A common evaluation sheet and criteria were used by all testers (Appendix A). The Piagetian test was administered several days prior to the administration of the Preconceived Knowledge Test at the home schools of the fourth grade subjects and took approximately 15 to 20 minutes per student to complete. The three student research assistants and this researcher required one full school day in the "gifted" building and, likewise, one full school day in the "non-gifted" building. A large unused classroom was secured and tables were set up in each corner to insure privacy. To reduce distraction, portable screens were arranged to separate the four testing sites from each other. The Piagetian-type tasks selected to measure concrete ability included the following:

(1) Conservation of number using black and red checkers

Six black checkers were lined up evenly in a straight line and eight red checkers were clustered to one side. The child was then requested to line up the same number of red checkers as black. If the child was not able to demonstrate one-to-one correspondence, this activity was stopped at this point. However, if the child did demonstrate one-to-one correspondence, the red checkers were stacked into a vertical column by the tester and the child was asked whether there were fewer, the same, or more red checkers than black ones. The child was asked to explain his/her answer. Finally, the black checkers were moved into a tight line, and the red checkers were spread out far apart across the top of the table. The child was asked whether there were fewer, the same, or more red checkers than black ones. Again the child was asked to explain his/her answer.

(2) Conservation of length using two identical strips of colored paper positioned one ahead of the other

Two strips of different colored paper, each 12 inches long and one inch wide were given to the child who was asked if he/she could show the tester whether the strips were equal in length or one longer than the other. If the child could not show that both strips were of equal length, the activity was stopped. The tester then placed both strips on the table in front of the child with one 6 to 10 inches ahead of the other. The child was asked to pretend one strip was the distance he/she had to walk to school, and the other strip was the distance a friend had to walk to school. The student was then asked if he/she walked a shorter, the same, or a greater distance to school than did his/her friend. The child was asked to explain his/her answer.

(3) Conservation of substance using two different shapes of equal amounts of clay

Two balls of clay about the size of a golf ball and of equal size but different color were given to the child, and he/she was asked to confirm their equality in size. If the child insisted one was larger than the other, he/she was asked to make them equal. The child was then asked to roll one of the balls of clay into a long, skinny snake. The child was then asked if the snake had less, the same, or more clay than the ball. The child was asked to justify and explain his/her answer.

(4) Conservation of area using two identical pieces of green paper representing grass and smaller squares

representing buildings to be placed on the grass

The child was given the two identical green sheets of construction paper (8½x11) and asked to confirm that they were the same size. The child was asked to pretend that these green sheets were a field of grass. The child was also shown six identical 1-inch squares cut from brown paper and asked to pretend that the brown squares represented houses or barns. After the child had confirmed that the six brown squares were equal in size, the tester placed three of the squares very close together on one of the green sheets, and the remaining three brown squares were placed as far apart as possible on the second green sheet. The student was then asked whether there was less, the same, or more grass to mow in one field than in the other. Again the child was asked to explain his/her answer.

(5) Conservation of volume using objects with equal volumes but different weights

Two identical small pill vials were used as equal volumes. One was completely filled with led shot and the other was approximately one-quarter filled. Two 100 ml graduated cylinders were filled to the 70 ml mark with colored water, with a rubber band placed around each graduated cylinder to mark the level of the colored water.

The student was asked to confirm if both graduated cylinders contained the same amount of water and if both pill vials were equal in size but noticeably different in weight. The child was encouraged to make whatever modifications were necessary. The child was asked to predict what would happen to the level of the colored water when the lighter pill vial was lowered by a thread into one of the graduated cylinders. The child was asked to reposition the rubber band to the level he/she thought the water would rise.

The child was then asked to predict what would happen when the heavier pill vial was lowered by a thread into the other graduated cylinder. Again the child was asked to reposition the rubber band to the level he/she thought the water would rise. The child was asked to explain his/her predictions. Following the child's explanation the tester lowered the heavier pill vial into the graduated cylinder and allowed the student to compare the actual rise in the water level with his/her previous positioning of the rubber band to the predicted level. The child was asked to explain the results.

(6) States of transformation using the falling pencil example

Six index cards, each with a drawing of a pencil in a different position representing movement from a vertical position as a pencil falls to the horizontal position on the table, were used. An actual pencil was held vertically on the table by the tester, and the child was asked to observe the pencil as it was released and allowed to fall freely to its horizontal position. The six index cards were then placed in front of the child in random order. The child was asked to arrange the six cards to show how the pencil fell. The child was asked to explain his answer.

The testers, having received some training in the Piagetian-type interview protocol (Piaget, 1965), decided whether the students' responses to the questions and tasks suggested concrete operationalism. Since there is no collection of tasks "certified" as an official instrument for measuring a child's level of Piagetian intellectual development, the questions used in this portion of the study were selected because of their popular use in the research literature (Trojcek, 1979). The testers were evaluating the student responses in terms of "random answers, romancing reaction, suggested conviction, liberated conviction and spontaneous conviction" (Piaget, 1965, pp. 10-32). The students were asked to respond to six conservation and transformation tasks, and the tester was asked to categorize each answer according to Piagetian protocol and to respond on the evaluation form (Appendix A).

If a student was able to demonstrate the conservation of number, length, area, volume, and transformation, he/she was judged to be a concrete operational thinker. Students who were not able to complete the tasks or gave incorrect reasons for their answers were eliminated from the study. In order not to include fourth-grade students whose concrete operationalism was in doubt, this researcher decided to include only those students who demonstrated successful conservation on all required tasks.

The Piagetian Test for Formal Operationalism used to further establish the formal operationalism of the eleventh-grade subjects, was derived from work by Renner and Stafford (1972). Research by Renner (1976) and Shayer and Adey (1983) indicates that the populations of tenth, eleventh, and twelfth graders who have achieved formal operationalism are not as large as originally described. However, their studies indicate that formal thinkers are found in these grades. As was mentioned previously, the eleventh grade was chosen for this study because physics is offered during this period. The four problems used in this portion of the study were designed to evaluate the level of formal operational thought. Applying the Piagetian theory of intellectual development, Renner and Lawson (1973), Champagne and others (1981), and Shayer and Adey

(1983) correlated science learning and student achievement with specific differentiated levels of formal thought. The questions used in the formal reasoning test evaluated three separate and major intellectual structures. These included the separation and control of variables, combinatorial logic, and proportional reasoning. The Piagetian task analysis scales used for measuring these structures were developed, tested, and validated by Renner, Prickett and Renner (1977) (Appendix A).

Two questions used were called "The Shadows Incident" and "The Frogs Incident." These were evaluated using the Proportional Reasoning Scale which is similar to the Piagetian Interview Point System (Inhelder & Piaget, 1958) and which is composed of seven categories to which points are assigned. The other two questions on the Formal Reasoning Test were the "Rock Incident" and the "Geranium Incident," each requiring a separate scoring scale. The "Rock Incident" utilized a student's combinatorial logic structure, and the "Geranium Incident" required the use of the separation and control of variable structures. The Piagetian test used to establish formal operationalism was administered to the gifted and non-gifted samples of eleventh graders. The subjects were drawn from three separate physics class sections taught by the same teacher. Since the Piagetian formal reasoning test required written responses, the three physics sections were tested separately. Each section was tested during successive physics classes in order to minimize communication between the sections concerning the test. The questions were reproduced so that each student was able to respond individually in writing on the test form. The individual responses were read and evaluated by this researcher, the high school physics teacher, and a Wilkes College psychology professor. The variation in the numerical scores recorded by the three evaluators were averaged and used as a single score in the analysis of the data. Only those eleventh graders who demonstrated formal operationalism as determined by the three evaluators were included in the study. A copy of the Formal Reasoning Test, the evaluative criteria, and the scoring scale are included in Appendix A.

The newly compiled Preconceived Knowledge Test was administered to the fourth and eleventh grade, using the same procedural criteria. The test consisted of nine written questions and five task questions dealing with motion of common objects involving certain mechanical concepts. The Preconceived Knowledge Test was administered individually to all subjects in the gifted and non-gifted fourth and eleventh grade sample groups. The average time required for each subject to complete the written and task portions of the Preconceived Knowledge Test was 30 minutes. The Preconceived Knowledge Test was administered initially to the fourth-grade sample groups during the last week in April and first week in May, 1984. This researcher administered and evaluated the Preconceived Knowledge Test for all sample groups in the study. It required six full school days during a 2-week period to test the two fourth-grade sample groups. The eleventh-grade sample groups of gifted and non-gifted students were tested during the second week in May, 1984. This required five full school days, testing approximately 10 students a day.

The first question on the written portion of the test involved a picture of a pendulum swinging through its various positions with the direction of motion indicated (Appendix B). The students were asked to trace the trajectory the pendulum bob would follow if the string were cut in the last position shown. This question was used by Caramazza et al. (1981) while studying preconceived views of 50 college undergraduates, most of whom had taken physics in high school and/or college. Their study was part of a project to characterize internal representations of the physical world.

The second written question dealt with a picture of a rocket ship moving sideways with a constant motion; its rockets were not firing. In a second picture, the rockets were firing in addition to the sideways motion (Appendix B). The students were asked to trace a line to a third picture of the rocket to represent its total motion. This question was used by Clement (1982) in a study examining the preconceptions of 150 college pre-physics engineering students and dealing with introductory mechanics.

The third written question involved a picture of a cannon ball fired horizontally from a high cliff (Appendix B). The students were asked to trace its path through the air as it fell to the ground. A similar question was used in a study by McCloskey and others (1980) and Clement (1982). One purpose of their studies was to examine the pre-Newtonian views held by college level students studying physics.

The fourth question involved a picture of a person swinging an object on the end of a string in a horizontal circle over their head (Appendix B). The students were asked to trace the path the object would take if the string broke at a particular point. The students were told to consider the motion as if it were viewed from above. A similar question was used in studies by Clement (1982) and McCloskey (1983) in attempting to determine the preconceived views concerning mechanical concepts held by high-school and college students.

The fifth and sixth written questions showed a ball bouncing across a table top. The position of the ball was indicated in two possible positions (Appendix B). These included downward motion and an upward motion. The students were asked to draw an arrow representing the force or forces on the ball in each position only if they thought there was a force on the ball. This quertion was utilized by Viennot (1979) and Sjoberg and Lie (1981) in studying European college and high school students. The major focus of their studies was to examine the models used by students in reconciling motion with force. The studies showed that students tend to believe that the force on a body is always in the direction of its motion.

The final three questions on the written portion was a picture showing a ball being thrown vertically upward and returning to the ground (Appendix B). The ball was shown in an upward motion, at the peak of that motion, and in a downward motion. Again the students were asked to draw an arrow representing the force or forces on the ball at each position. They were asked to draw an arrow only if they thought there was a force on the ball in these positions. This question was included in a study performed by Clement (1982) in examining the preconceptions of college students in introductory mechanics.

The task portion of the preconceived knowledge included five activities which involved hands-on experience for the subjects. The first task (Question 10) required the student to drop a lead and aluminum ball, both about the size of a golf ball, into a box filled with sponge rubber. Initially the students were asked about the weights and were allowed to determine whether one was heavier than the other. A simple, pan-balance scale was available for the skeptics. Initially the students were asked to predict how both balls would fall if released at the same time. Following their predictions, they were asked to release the aluminum and lead balls together and to observe the motion. They were asked whether their predictions were accurate and to explain the results. This exercise was used by Champagne, Klopfer, Solomon, and Cahn (1980) in a study comparing students' preconceived views of mechanical concepts with their comprehension of science experiments.

The second task (Question 11) required the students to predict the path of a small pea-sized ball-bearing as it emerged from the distal end of a plastic tube which was coiled into a three-quarter circle loop and lying horizontally on the table. This tube was attached to a platform (Appendix B). The students were asked to make their predictions by using a crayon to trace the expected path of the ball-bearing on a sheet of paper positioned under the apparatus. Following the students' prediction of the path of the ball as it emerged from the distal portion of the plastic tube, they were allowed to drop the ball-bearing in the elevated end of the tube. The students were asked to observe the path of the ball as it emerged from the opposite end. They were asked to compare their prediction with their observation and to explain differences, if there were any. This problem was utilized by McCloskey and others (1980) in a study of preconceived views concerning circular motion held by students across diverse age groups.

The third task (Question 12), also used by McCloskey et al. (1980) in their study of high school and university students, involved a plastic tube coiled into three circular loops lying horizontally on the table (Appendix B). The students were asked how the ball-bearing would travel after it was dropped in the elevated end of the coiled tube and allowed to roll out the opposite end. Again the students were asked to predict the motion by tracing with a crayon the expected path of the ball-bearing on a sheet of paper placed near the distal end of the tube. The students were then asked to drop the ball in the elevated end of the coiled tube and to observe how the motion compared with their prediction; if there were a difference, and to explain the results.

The fourth activity (Question 13) involved rolling a small "puck" with a ball-bearing through a 90° segment of a circular track drawn on a poster board and lying in a horizontal position on the table (Appendix B). The students were asked to push the "puck" up to one edge of the circular segment and to release it so that it would cross the other side of the segment without touching either side of the curved pathway. The students were asked to explain whatever type of motion they attempted to impart to the "puck" and why it traveled as it did. McCloskey (1983) used this experiment at Johns Hopkins University with high school and college students studying the contrasts between student-held views of the mechanical world and first-hand observations.

The final task (Question 14) involved asking the students to walk at a normal pace holding a golf ball at their side. An empty 3-pound coffee can filled with sponge rubber was positioned on the floor. The students were asked to release the ball as they walked past the can so that the ball would fall into the can. The students were then asked where they believed the golf ball should be released in order that it would fall into the coffee can. They were asked to explain their answer. This activity was also used by McCloskey (1983) in a study of preconceived views of motion held by university and high-school students.

For the purposes of this study, responses to the nine questions and five tasks of the Preconceived Knowledge Test were considered either correct or incorrect according to protocol established by researchers presently studying preconceived knowledge of mechanical concepts (Champagne, et al., 1980C; Clement, 1982; McCloskey, 1983; McDermott, 1984; Viennot, 1979). All judgments regarding the correctness of the 14 responses were made by this researcher in order to minimize variations in bias and interpretations. For a response to be designated as correct, for purposes of analysis, only the answer had to be correct, regardless of the validity of the reasoning used in arriving at the answer. No effort was made to account for valid explanations given for incorrect responses or invalid explanations given for correct responses. The face validity of the Preconceived Knowledge Test, assumed as part of this study, was derived from those recent studies, previously cited, dealing with preconceived knowledge (Isaac & Michael, 1982). The reliability statistics concerning the items on the Preconceived Knowledge Test produced a Kuder-Richardson coefficient of .60584.

Method of Analysis

A purpose of the present study was to examine the relationships between giftedness, as defined by the site district, and the level of preconceptions of mechanical principles as measured by a Preconceived Knowledge Test. The student responses on the Preconceived Knowledge Test were tested as the dependent variable and giftedness and grade-level as the independent variables. The present study examined simultaneously two independent variables, namely giftedness and grade-level, therefore, it was decided to utilize the chi-square analysis in comparing responses given by subjects of the four sample groups on the Preconceived Knowledge Test. The questions represented different concepts of motion, therefore, it was decided to separately analyze the relationship between the four sample groups for each of the individual questions of the Preconceived Knowledge Test.

The data were presumed to fit 2 x 2 contingency tables with 1° of freedom on each of the four analyses. Consequently, the Yates correction was utilized and the test for significance was chosen at the 1%-level (Ferguson, 1966). The responses on each question of the Preconceived Knowledge Test given by each subject tested were scored as either correct (+) or incorrect (0). The chi-square method was chosen because it relates only to frequency data and required that each individual event is independent of each other. According to Isaac and Michael (1982), the essential restrictions of the Chi Square Analytical

Method are that the individual responses are independent of each other, that the data must be categorized in some logical or empirical form, that the sum of the expected and observed frequencies be equal, and that the algebraic sum of the discrepancies between the observed and the corresponding expected frequencies be zero. Since the hypotheses under investigation in this study were stated as null hypotheses and assumed to be true, a calculated value of χ^2, which was greater than the critical value required for significance (p=.01) for 1° of freedom would require a rejection of the null hypotheses. In order to test the first null hypothesis, the gifted samples were compared with the non-gifted samples on their responses to questions on the Preconceived Knowledge Test. In a similar fashion, the second null hypothesis was tested by comparing responses of the fourth grade samples with those of the eleventh grade samples. This method allowed for examining the interaction between the cells of the 2 x 2 tables with regard to the scores on the Preconceived Knowledge Test in order to test the hypotheses. However, the small size of the sample groups tested pose several intrinsic problems with this analysis. The most obvious is that close agreement between the observed and expected values may be highly improbable, consequently, a small value of χ^2 casts suspicion on either the data or the calculations (Ferguson, 1966; Upton, 1978). The analysis of the data was made by the Data General MV 10,000 at the Wilkes College Computer Center with the assistance of the Computer Center staff. The software program utilized was the BMDP statistical software package from the Regents of University of California (1983). A further discussion and delineation of the statistical treatment and interpretation of the data is included in Chapter 4.

Summary

The purpose of this chapter was to describe the statistical parameters of this study. These included the selection of the site school district, the four sample groups and the rationale for selecting the groups. The present study involved the use of two Piagetian-type tests to measure concrete and formal operationalism. These tests, along with the testing procedure and protocol, were previously described. The third instrument, the Test for Preconceived Knowledge of certain mechanical principles was gleaned from the current research on preconceived knowledge and tested for suitability in this study through a pilot study. The statistical treatment of the data resulting from the actual study was also described, as was the rationale for the choice. The next chapter records the results of the investigation by describing the statistical analysis undertaken to evaluate the data, including the theoretical and statistical assumptions made to examine the relationships between giftedness and preconceived knowledge of mechanical concepts and also between Piagetian development and preconceived knowledge of mechanical concepts.

Chapter 4

ANALYSIS AND DISCUSSION OF DATA

The role of preconceived knowledge dealing with mechanics has become a primary focus for science educators and learning psychologists. Since Newtonian mechanics serves as the basis for the rest of scientific pedagogy, it is incumbent on science educators at all levels to be concerned with how and when students actually conceptualize the fundamental concepts of motion.

A purpose of this study was to examine differences in the levels of preconceived knowledge of mechanical concepts among gifted and non-gifted sample groups of fourth and eleventh graders. The fourth grade level was chosen because according to Piaget (1958) and Shayer and Adey (1983), most fourth grade students will have achieved concrete operationalism. A second purpose of this study was to examine the role of physics instruction in resolving non-Newtonian preconceptions, therefore, the eleventh grade was chosen as the other sample group because physics was taught to them at the site district. Another reason for selecting the eleventh grade was that according to Piaget (1958) and Shayer and Adey (1983), most eleventh graders will have achieved formal operationalism.

At the present time, no validated or tested instrument exists for the measurement of preconceived knowledge dealing with mechanical concepts. Consequently, this researcher compiled a series of nine written and five task questions involving certain fundamental concepts of motion. Following a pilot study, these 14 items were very carefully selected from several significant studies on preconceived knowledge involving mechanics.

The items used in the Preconceived Knowledge Test were derived from studies done by Champagne et al. (1980b), Clement (1983), McCloskey (1930), McDermott (1984), Trowbridge (1980), and Viennot (1979). Prior to the administration of the Preconceived Knowledge Test, it was first determined by using Piagetian tests that all fourth-grade subjects were concrete operational and similarly that the eleventh-grade subjects were formal operational. In order to preserve the homogeneity of the eleventh grade population, only those taking physics concurrently were involved in the study.

The 14 test items on the Preconceived Knowledge Test represented several different mechanical concepts such as linear motion, free fall, projectile motion, uniform circular motion, and forces. The subjects were scored on each item of the Preconceived Knowledge Test as being either correct or incorrect with no regard for the validity of the reason for their answer. Consequently, the data represented the number of correct responses given on each item by each subject; and since each question represented a different concept of motion they were analyzed separately.

In order to examine the differences between the sample groups in their responses to items on the Preconceived Knowledge Test, the chi-square analysis was used. Because the data fit a 2 x 2 contingency table with 1° of freedom, the Yates correction was utilized (Berenson, Levine, & Goldstein, 1983). The null hypotheses contained in this study were measured for significance at the 1% level.

Analysis of Data

Table 1 shows the frequency of correct responses on each of the 14 test questions for the gifted and non-gifted samples of the fourth grade samples. The probabilities shown in Table 1, resulting from a chi-square analysis, demonstrate no significant difference at the .01 level between the gifted and non-gifted fourth grade sample groups for any of the 14 test questions. Based on this analysis on the first null hypothesis was accepted for all of the test items for the fourth grade gifted and

Table 1

Correct Responses on Preconceived Knowledge Test for Fourth Grade Sample: Chi-Square Analysis for Giftedness vs. Responses to Question

d.f. = 1

Question #	Gifted N=29		Non-Gifted N=24		Yates χ^2	p.
	n	%	n	%		
1	9	31	3	12	1.626	.2022
2	7	24	2	8	1.341	.2469
3	19	65	14	58	.064	.8007
4	9	31	4	17	.791	.3738
5	8	27	4	17	.379	.5380
6	3	10	2	8	.000	1.000
7	3	10	1	4	.106	.7450
8	19	65	13	54	.312	.5763
9	28	96	23	96	.000	1.000
10	6	21	0	0	3.728	.0535
11	10	34	15	62	3.089	.0788
12	8	27	8	33	.023	.8783
13	4	14	7	29	1.068	.3014
14	14	48	16	67	1.137	.2863

non-gifted samples. Table 2 represents the analysis of the data resulting from the administration of the Preconceived Knowledge Test to the eleventh grade gifted and non-gifted samples. The chi-square analysis of this data did not indicate any significant differences at the 1% level for any of the 14 test items. Consequently, the first null hypothesis was also accepted for the eleventh grade gifted and non-gifted samples on all the test items.

A second focus of this study was to compare the level of preconceived knowledge between gifted fourth and eleventh graders and between non-gifted fourth and eleventh graders. The purpose of this part of the study was to examine the role of intellectual maturity and development in the retention of preconceived knowledge concerning concepts of motion. In order to investigate this question the data were analyzed comparing the results on the Preconceived Knowledge Test of the fourth grade samples with those of the eleventh grade samples. As with the previous comparison, the chi-square was used to analyze the results comparing the fourth and eleventh grade samples.

Table 3 shows the data and the analysis for the fourth grade gifted sample vs. the eleventh grade gifted sample on their responses to the questions of the Preconceived Knowledge Test. One might assume the eleventh

Table 2

Correct Responses on Preconceived Knowledge Test for Eleventh Grade Sample: Chi-Square Analysis for Giftedness vs. Responses to Question

d.f. = 1

Question #	Gifted N=25		Non-Gifted N=24		Yates χ^2	p.
	n	%	n	%		
1	15	60	11	46	.500	.4796
2	6	24	8	33	.165	.6843
3	21	84	21	87	.000	1.000
4	16	64	11	46	.982	.3218
5	4	16	8	33	1.163	.2809
6	2	8	7	29	2.383	.1226
7	2	8	4	17	.239	.6247
8	11	44	12	50	.018	.8931
9	24	96	21	87	.319	.5724
10	14	56	5	21	4.983	.0256
11	20	80	17	71	.171	.6791
12	18	72	13	54	.996	.3182
13	14	56	14	58	.000	1.000
14	23	92	19	79	.766	.3816

Table 3

Correct Responses on Preconceived Knowledge Test for the Gifted Samples: Chi-Square Analysis for Grade Level vs. Responses to Question

d.f. = 1

Question #	4th Grade N=29		11th Grade N=25		Yates χ^2	p.
	n	%	n	%		
1	9	31	15	60	3.464	.0627
2	7	24	6	24	.000	1.000
3	19	65	21	84	1.523	.2172
4	9	31	16	64	4.167	.0317
5	8	27	4	16	.480	.4884
6	3	10	2	8	.000	1.000
7	3	1[illegible]	2	8	.000	1.000
8	19	65	11	44	1.721	.1895
9	28	96	24	96	.000	1.000
10	6	21	14	56	5.744	.0165
11	10	34	20	80	9.497	.0021*
12	8	27	18	72	8.904	.0028*
13	4	14	14	56	8.947	.0028*
14	14	48	23	92	9.959	.0016*

* $p < .01$

grade gifted sample concurrently taking physics, who have had 7 additional years of formal science and mathematics instruction, would do significantly better than their fourth grade counterparts on identical questions dealing with fundamental mechanical concepts. Table 3 suggests this may not necessarily be the case. A comparison of these sample groups showed no significant difference at the 1% level on Questions 1 through 10 of the Preconceived Knowledge Test. However, on Questions 11 through 14 (all task questions) significance was achieved at the 1% level. While it might be tempting to speculate that gifted formal thinkers do better than gifted concrete thinkers on task questions but not on written questions; this researcher is not prepared to make this conclusion. The limitations of the study, with respect to sample size, prevent this generalization. It is interesting to note from Table 3 that for Questions 5, 6, 7, and 8, a larger percentage of the fourth grade sample answered correctly than did the eleventh grade and on Questions 2 and 9, the percentages were equal. This would seem to suggest that the number of science courses taken and the level of intellectual and cognitive maturity does not necessarily enhance a student's understanding of certain fundamental mechanical concepts. In this case, the data would seem to suggest that confusion with mechanical concepts might increase with age and additional instruction.

On the basis of the analysis of the data shown in Table 3, the second null hypothesis was accepted for Questions 1 through 10 for the gifted samples. However, significance at the 1% level was achieved for Questions 11 through 14; therefore, the second null hypothesis was rejected for these questions. As was mentioned previously, Questions 1 through 9 were the written questions and Questions 10 through 14 were the task questions. Although Question 10, the first of the task questions, was not significant at the 1% level, it was significant at the 2% level ($\underline{p}$ = .0165). If, for purposes of discussion, Question 10 was included with those that did achieve significance at the 1% level (Q 11-14), it would be possible to say that the second null hypothesis was rejected for the task questions; however, it was not rejected for the written questions on the Preconceived Knowledge Test between the fourth and eleventh grade gifted samples.

In an attempt to extend the comparison between concrete and formal thinkers on their responses to questions on the Preconceived Knowledge Test, a chi-square analysis was carried out for the non-gifted samples of fourth and eleventh graders. This was done to further test the second null hypothesis. Based on the analysis of the data in Table 4, it was shown that there was no significant

Table 4

Correct Responses on Preconceived Knowledge Test for the Non-Gifted Samples: Chi-Square Analysis for Giftedness vs. Response to Question

d.f. = 1

Question #	4th Grade N=24		11th Grade N=24		Yates χ^2	p.
	n	%	n	%		
1	3	12	11	46	4.941	.0262
2	2	8	8	33	3.158	.0756
3	14	58	21	87	3.798	.0513
4	4	17	11	46	3.491	.0617
5	4	17	8	33	1.000	.3173
6	2	8	7	29	2.188	.1391
7	1	4	4	17	.893	.3447
8	13	54	12	50	.000	1.000
9	23	96	21	87	.273	.6015
10	0	0	5	21	3.572	.0588
11	15	62	17	71	.094	.7595
12	8	33	13	54	1.354	.2445
13	7	29	14	58	3.048	.0809
14	16	67	19	79	.422	.5160

difference at the 1% level in responses on any of the 14 questions between the fourth and eleventh grade non-gifted samples. This would seem to suggest that the eleventh grade non-gifted students, despite the fact that they were studying physics and were demonstrated formal thinkers experienced the same difficulties with certain fundamental mechanical concepts as did their fourth grade counterparts. Consequently, the second null hypothesis was accepted for all of the 14 test items.

Discussion of Data

The research findings of those studying preconceived knowledge concerning mechanical concepts and its role in the learning of science tend to support the results of the present study. Interest in preconceived knowledge (previous learning) as a deterrent to present and future learning is not new. The psychologist, Charles H. Judd (1915), criticized science textbooks and teachers in the early part of this century for presenting too many terms and requiring the student to memorize them only to give them back on command with little concern for understanding or generating enthusiasm. More recently several groups, from whose studies were derived the questions used in the present study, have investigated the difficulties students have with basic Newtonian mechanics (Champagne et al., 1980; Clement, 1982; McCloskey et al., 1980; McDermott, 1984; Viennot, 1979).

The first question used in the present study asked the students to draw the path that a pendulum bob would follow if the string were cut just having passed through its lowest position. Only 46% of the non-gifted and 60% of the gifted eleventh graders answered correctly (Table 2). The fourth graders did not do as well as the eleventh graders on this question since only 31% of the gifted and 12% of the non-gifted answered correctly (Table 1). However, this was not true for all questions; Tables 3 and 4 indicate that in some cases a larger percentage of fourth graders answered correctly than did their eleventh grade counterparts. This question was derived from a study by McCloskey et al. (1981) examining preconceived knowledge among 50 undergraduates at Johns Hopkins University. They found that only one-fourth of their subjects answered correctly. McCloskey and his colleagues concluded their subjects retain a well-integrated system of beliefs concerning the motion of ordinary objects that is in direct conflict with the accepted view.

The second question of the test required the students to draw the path of a spaceship moving sideways through space at the moment the engines are fired. Clement (1982) posed this question to 150 freshmen entering the Engineering Department at the University of Massachusetts and also to 43 engineering upper-classmen who had a course in Newtonian mechanics. His results show that 9% of the entering freshmen and 19% of the upper-classmen answered correctly and an additional 27% of the freshmen and 37% of the upper-classmen answered partially correct. The results indicate that nearly 75% of the entering freshmen and nearly 50% of the engineering upper-classmen did not answer correctly. This question (Q2), in the present study, was answered correctly by less than 20% of the fourth grade samples and by only approximately 30% of the eleventh grade samples. This would seem to suggest that Clement's subjects experienced the same difficulty that the fourth and eleventh grade subjects of the present study did.

Question 3 of the test showed a cannon being fired horizontally from the top of a cliff. The students were asked to draw the path of the cannon ball as it traveled through the air and fell to the ground. Green et al. (1980) presented this question to 48 undergraduate students at Johns Hopkins University. Seventy-five percent of their subjects thought the cannon ball would follow a parabolic path, more or less; however, 25% thought the ball would travel out part of the way, then fall vertically downward. This was reasonably consistent with the present findings where approximately 60% of the fourth grade and 85% of the eleventh grade samples sketched a parabolic-like path for the projectile. Those who did not, as in Green's study, showed the ball moving out part of the way and then falling vertically downward.

Green et al. (1980), in the same study mentioned above, used Questions 4, 11, and 12 of the Preconceived Knowledge Test. Question 4 showed an object being twirled around in a circular horizontal path at the end of a rope. The students were asked to draw the path the object takes when the rope is cut. Questions 11 and 12 are task-questions and required the students to predict the path a ball would take after rolling through a circular plastic tube placed horizontally on the table. These three questions deal with the motion of an object moving in a circular path after the constraints have been removed. Green et al. (1980) showed that half of his college sample thought the ball would continue in a circular path after emerging from the coiled plastic tube (Q11, Q12); 30% thought the ball, being swung around in a circle, would continue its curved path even after the rope was cut. These findings are supported by the data resulting from the present study where approximately 75% of the fourth graders and 50% of the eleventh graders thought the objects in Questions 4, 11, and 12 would continue in a curved path after the constraint was removed.

Champagne et al. (1980) have reported that samples of college students with and without physics training have difficulty with free fall problems. They showed that nearly one-half of their subjects thought a heavy ball would hit the ground before a light one. The results of the present study indicated that slightly more than 50% of the subjects, not unlike Champagne's study, thought a heavy ball would fall faster than a lighter ball of equal size (Q10).

Clement (1982) and Viennot (1979) noted an Aristotelian-Impetus model was utilized by high-school students when trying to explain the motion and forces involved with objects thrown into the air. Questions 5, 6, 7, 8, and 9 of the present study involved a ball being thrown in the air depicted in several pictures showing the ball traveling upward and then falling to the ground and also bouncing up from the floor. The students were asked to sketch an arrow showing the force or forces acting on the ball in the various positions. These identical questions were used in several studies; Sjoberg and Lie (1981), Minstrell (1982), and Clement (1982). They demonstrated that students from diverse sample groups confuse the direction of motion with the direction of forces acting on the object. Clement (1982) asked 150 students to draw the direction of the force or forces on an object thrown up into the air and in various positions as it fell to the ground. Clement found that over half of his college level subjects confused the direction of motion with the direction of the force on the object. The data resulting from the present study show similar confusion among students of all sample groups (Tables 3 and 4). Viennot (1979), in a similar study using 2,000 Belgian, French, and British students enrolled at the University of Paris, reported that 50% of his students confused the direction of motion with the direction of forces acting on the object.

Questions 13 and 14, the final two questions of the present study, were tasks whose successful completion depended upon the students' understanding of Newton's First Law of Motion, which states that an object set in motion, ignoring friction, would stay in motion. Question 13 required the students to roll a puck through a quarter circular track (see Chapter 3). Tables 3 and 4 show that 80% of the fourth grade and 40% of the eleventh grade students were unable to correctly complete the task. This question was used by McCloskey (1983) in studying misconceptions held by college and high-school students; he found that over one-third of all students in his study gave an incorrect solution to the task. Incidentally, the incorrect solution given most often by students on

McCloskey's study, which involved trying to give the puck an impetus of curved motion to carry it through the curved path, was identical to the results of this study.

McCloskey (1983) also used the task problem where his subjects were asked to run with a ball in their hand and to release the ball so that it would fall into a basket situated on the floor. McCloskey found that only 45% of his college-level population knew the ball had to be released before the basket, owing to the forward motion, in order for it to fall in the basket. The findings of the present study do not seem to support McCloskey's data on this queston (Q14) since 92% of the gifted and 79% of the non-gifted eleventh graders and 48% of the gifted and 67% of the non-gifted fourth graders involved in the present study knew the ball had to be released before the target was reached in order to compensate for the ball's forward motion. This was a much larger percentage than McCloskey found in his study. Each student, in the present study, was questioned for an explanation of his/her choice of action and this researcher is convinced that the correct choice of action was made for the correct reasons. This apparent discrepancy points up the need for additional research with larger samples and some sort of standardization in measuring a student's grasp of the preconceptions utilized in their attempt to understand the physical world. The majority of studies conducted by those researchers presently investigating preconceived knowledge including the present study, tend to use small samples ($\leq$ 200) which may contribute to such discrepancies in the results.

The findings of the present study are generally consistent with other recent studies (McDermott, 1984) indicating that students do indeed use an Aristotelian-Impetus model to justify their observations and to make predictions concerning mechanical problems. Consequently, the Newtonian model, which teachers work diligently to impart to their students as do textbooks and curricular materials, is rarely utilized by the students to justify their experiences in the physical world despite intensive training in the physical sciences (McCloskey, 1983; Minstrell, 1984).

The present study examined preconceived knowledge concerning mechanics among gifted samples, consequently, research relevant to giftedness is important to this discussion of the data. Those researchers studying the intellectual and non-intellectual traits of giftedness have shown that giftedness is too complex for meaningful measurement exclusively with IQ and achievement tests (Sternberg, 1982). According to Delisle and Renzulli (1982), most schools in this country use a criterion for qualification for placement in a gifted program based almost exclusively on IQ score. The present study showed that the site district uses a similar criterion. The gifted subjects in the present study were demonstrated to have a minimum IQ of 130, the cut off for placement in the gifted program in the site district.

Scientists and learning theorists have long been interested in the role of giftedness, as measured by standardized tests, in understanding scientific concepts (Getzels & Jackson, 1962). This question has been further delineated to include the role of divergent and convergent thinking. According to Biehler and Snowman (1982), the unconventional, divergent thinkers such as Edison and Einstein, to mention a few, are likely to be judged as poor learners and inattentive. Conversely, teachers generally nominate the more conventional convergent thinker as their best student. However, according to Terman and Oden (1959), these persons rarely make original contributions to their fields. A primary focus of this study was to examine the level of preconceived knowledge concerning certain mechanical concepts among gifted students. It was hoped the present study would contribute to an expanded model of giftedness which would include the preconceived knowledge of mechanical concepts held by the students.

For purposes of discussion several studies examining expanded models of giftedness are included. Recent studies suggest assumptions made and held by the educational community about the generalized learning skills of the "gifted" student may not be justified. A study by Terman (1959) showed that students with average or even possibly below average IQ may do better on certain creative tasks or strategies than do gifted students. Similarly, Renzulli (1978) had cautioned educators not to determine a priori giftedness upon IQ alone. For to do so, according to Renzulli, would ignore students who possessed intellectual and non-intellectual skills not measured exclusively by tests of intelligence or creativity. Ludow and Woodrum (1982), examining the problem-solving strategies of gifted and average learners (determined by IQ scores), showed that gifted learners at the elementary level do not necessarily develop problem-solving abilities as a natural consequence of higher IQ's. Delisle and Renzulli (1982), using various behavior models to determine giftedness rather than personality and intellectual traits, have shown that a student's concept of self is more likely to result in academic success than the IQ or rank in class. Their study showed that 56% of their study population, consisting of middle and junior-high school students, who do not meet the IQ requirements for inclusion in a gifted program demonstrated gifted behavior on tasks and projects of interest to the student. Delisle and Renzulli (1982) suggest that students in a traditional gifted program (based on IQ tests) lack both direction and knowledge of their roles as "gifted" students. Consequently, Delisle and Renzulli (1982) agree with Terman (1959) that the exclusive and stringent use of IQ scores or achievement tests for identifying the gifted students is indefensible on the basis of current research findings.

A recent study by Davidson and Sternberg (1984) examining the role of "insight" in intellectual giftedness revealed that a student's "insightful" grasp of a particular question or problem is not a direct function of either IQ or grades. In some cases the so-called average student seemed to demonstrate a greater "feeling" for the question or problem than did the gifted student. This would certainly support the findings of the present study that understanding of physical concepts derived from preconceived notions are not necessarily facilitated by intelligence based on IQ socres.

Summary

Everyday life provides students from preschool age to university level with an infinite variety of experiences and observations dealing with motion. It is upon these personal observations that students build their models which they then use to generalize about the physical world (McDermott, 1984). These personal observations provide the student with some intuitive knowledge about motion (Einstein & Infeld, 1938). This and other recent studies have shown the form or forms of this knowledge are not clear. However, several observations resulting from the present study are clear, namely, this knowledge is more an Aristotelian-Impetus model than Newtonian; it is extremely resistant to change despite decades of unprecedented curriculum reform; and, it is held and utilized by students from diverse backgrounds. Studies of preconceived knowledge of mechanical concepts, in addition to other areas of science, have provided an exciting perspective for curriculum and teaching reform. Science educators from the elementary to the graduate school level need to know what knowledge the students bring with them to the classroom and how this knowledge affects future learning.

The present study attempted to examine the preconceived knowledge of certain mechanical concepts between gifted and non-gifted samples. The analysis of the data from these comparisons did not yield significance at the 1% level on any of the 14 questions. This resulted in the first null hypothesis not being rejected for either the fourth or eleventh grade samples. These findings are supported by recent studies which have investigated and expanded non-psychometric models of giftedness (Davidson &

Sternberg, 1984; Delisle & Renzulli, 1982; Sternberg, 1982; Terman, 1959).

The present study also attempted to compare preconceived knowledge of certain mechanical concepts between concrete and formal thinkers. The analysis of the data resulting from this comparison showed that, between the gifted samples of concrete and formal thinkers, significance at the 1% level was achieved on only four of the questions. The analysis of the data for the non-gifted samples of concrete and formal thinkers showed that significance at the 1% level was not achieved for any of the 14 items. As a result of these analyses, the second null hypothesis was not rejected for the non-gifted samples and was not rejected on 11 of the 14 items for the gifted samples. This would seem to suggest, within the limitations of the study, that students from samples of diverse intellectual development possess similar preconceived views about motion. Consequently, they experience similar difficulties when dealing with questions of fundamental concepts of motion. These findings are supported by recent studies on preconceptions involving the principles of Newtonian mechanics (Champagne, et al., 1980b; Clement, 1982; McCloskey, 1981; Minstrell, 1982; Trowbridge & McDermott, 1982; Viennot, 1979).

Chapter 5

DISCUSSION

Summary

At no time in recorded history has the growth of scientific knowledge been as rapid as in recent decades. Technology, resulting from this expanding scientific knowledge, seems to move at a rate which defies even the scientists' attempts to remain current. In spite of the revolutions occurring in modern science the average person's understanding of basic scientific principles is proportionately much less than at any other time (Weisskopf, 1979).

C. P. Snow (1960) warned Western cultures that this widening knowledge gap between the science community and the general population threatens its continued existence. One might assume that unprecedented activity in science and technology would precipitate necessary and effective reforms in educational syste .

Over 25 years ago, with the launching of Sputnik, a concerted effort was made in this country to improve science education on all levels. The focus of this effort was curriculum reform and teacher education. During this period the National Science Foundation expended 130 million dollars on curricular innovations and an additional 565 million on teacher-training activities designated to implement the newly developed curricula. According to Welch (1979), the Elementary and Secondary Educational Act of 1965 and other governmental agencies expended over an additional billion dollars per year, much of it going into science curricula improvement, including the purchase of materials.

What were the general consequences of the enormous and expensive undertaking? According to recent study by Welch (1979), this endeavor was a complete failure in terms of developing a more scientifically literate public. The same conclusion is supported by the report of the President's Commission on Excellence in Education (Nation at Risk, 1983). A conclusion common to these studies is that science curricula have very little or no impact on student-learning regardless of what variations are utilized. Consequently, even if we view these conclusions with extreme caution, it is apparent that, despite the concerted effort to reform science teaching, the results have been at best, a disappointment; and, at worst, a complete failure.

The researchers concerned with the ways students learn science have also demonstrated that curriculum innovations of the last 25 years have done little to abate the growing disinterest in science shown by students at all grade levels (Sagan, 1982; Shayer & Adey, 1983). An exception to this situation is evidence that elementary students in grades 4-6 demonstrate increased interest in science. Welch (1979) suggested this phenomenon may be proof that, quite apart from curriculum or methodologies, elementary school children begin their schooling with a natural interest in science.

It is not suggested that the waning interest in science was caused exclusively by the failure of curricula or teaching methodologies. An area of research, important to this problem and receiving increased attention, has been the role of preconceived knowledge in the learning of science. These include the origin of student-held misconceptions, the nature of these well-organized and complex schemata, the way students utilize these preconceived views in explaining their personal observations of the physical world, and the role these play in the learning of science.

It is no secret to educators and physicists that the most fundamental laws of mechanics are difficult to teach and to learn (Kolody, 1977). A study by Peters (1982) showed that even honors students had difficulty in learning basic physics. Recent studies have shown that students, at all levels, come to the classroom with a well established and structured set of essentially incorrect rules upon which they base their view of the physical world. It is believed this construct is derived from personal experiences and observations made by the students as they interact with the physical world. Students have experienced their world from their pre-operational beginning and, therefore, come to the classroom with personally developed ideas about the physical world (Piaget, 1957). From the teachers' point of view, these student-held views seem hazy, ill-informed, inappropriate, and downright incorrect. However, from the students' point of view, these constructs make more sense then what is taught in the classroom as a basis for understanding the physical world.

A frustrating aspect of this phenomenon is that these preconceived views, held by the students of diverse ages and intellectual levels, are resistant to change. Despite intensive exposure to traditional instructional methods, students tenaciously hold to their personally developed views (Champagne, et al., 1983b). In addition, studies have shown that preconceived views are not facilitative to the learning process. Students interpret experiments or textual examples in the context of their preconceived views rather than in the one intended by the experiment, the text, or the teacher (McDermott, 1984).

The problems that students have in learning physics are not confined to those originating from preconceived ideas or in the misinterpretations of daily experiences. Physics teachers have long recognized that students have difficulty with abstract concepts, such as relativity or quantum theory, for which there are few preconceptions. The learning of science has always depended on the ability to conceptualize the ideas and principles upon which the structure of science is built. If this is so, then instructional methodologies and curricular innovations must address the reality of preconceptions which students bring to the classroom. Studies have shown that presenting the correct information to students in a variety of formats seldom causes the student to reject his/her version of understanding the world in favor of the official Newtonian view (Champagne, et al., 1980b). An interesting aspect of this problem is that students of above average intelligence and from diverse age groups, experience similar difficulties with mechanical concepts as do their average counterparts (McCloskey, et al., 1981; Peters, 1982). This occurs despite the fact that students with above-average intelligence (gifted) tend to earn higher grades in science and elect to take a greater number of science courses across all grade levels. A central focus of this study has been to examine these preconceived ideas concerning mechanical concepts among gifted and non-gifted students across diverse age groups.

Purpose

The present exploratory study was undertaken to examine preconceived knowledge concerning certain mechanical concepts among gifted and non-gifted students from two diverse age groups. It is hoped this study may contribute to the ongoing effort to identify the nature and sources of certain preconceived views concerning Newtonian mechanics and the role these views play in the learning of science in the everyday lives of the students. The present model utilized by most school districts to identify gifted students for placement in special programs relies heavily on IQ scores and achievement tests (Delisle & Renzulli, 1982).

An attempt was made to demonstrate that intelligence, as measured by IQ score, does not facilitate the understanding of fundamental mechanical principles. This study challenges the present means of placing students in gifted science programs based solely on IQ scores and expands our present model of giftedness to include the students' repertoire of preconceived views concerning the physical world.

Sample

The subjects selected for this study were students from a single public school district in Northeastern Pennsylvania. The site district was chosen because of its full-time gifted program and because extensive testing is conducted in support of the program. The study examined preconceived knowledge among identified gifted and non-gifted students from two diverse levels of intellectual development. The fourth grade was chosen as one of the samples because literature supports the notion that most fourth graders (9 years olds) have achieved some measure of concrete operationalism (Piaget, 1971). The eleventh grade subjects were chosen for two reasons: first, because physics was offered during the eleventh year and the total eleventh grade study sample was taking a physics course with the same teacher; secondly, because the eleventh grade subjects were expected to demonstrate some level of formal operationalism (Shayer & Adey, 1983).

The fourth and eleventh grade sample groups of gifted and non-gifted students were matched to achieve similar socioeconomic backgrounds. This was done with the help of the principals and teachers involved with the subjects included in the study. Also the numbers of boys and girls in each of the four sample groups were approximately equal despite the fact that no effort was made for this balance and no distinction for sex was made in the analysis of the data. The present study was carried out during the last 2 weeks of April and the first 2 weeks of May 1984 and all the students included in the study were enrolled in the site district during the academic year, 1983-1984.

Description of Testing Procedures

This study involved the use of three instruments. These included a Piagetian-type test to measure concrete operationalism among the fourth grade subjects, a Piagetian-type test to measure formal operationalism among the eleventh grade subjects, and a Preconceived Knowledge Test administered to all subjects included in the study.

The students were administered the Piagetian-type test and the Preconceived Knowledge Test on an individual basis with no time limit. However, most of the subjects required approximately 15 to 25 minutes to complete the Piagetian test and an equal time to complete the 14 test items on the Preconceived Knowledge Test.

The Piagetian test, used to measure concrete operationalism, included the conservation tasks of number, length, area, and volume, and a transformation task (Trojack, 1979). Students who were not able to complete the tasks or who gave incorrect reasons for their choices were not included in the study.

In a similar fashion the eleventh grade sample groups were administered a Piagetian written test for formal operationalism, and those students who could not complete the questions or give appropriate responses were not included in the study. The Piagetian tests were administered and evaluated by this researcher and three senior psychology majors with previous experience in similar testing protocol. This aspect of the study was supervised by a Ph.D. in psychology with extensive experience in testing.

Central to this study were the results of the Preconceived Knowledge Test. This instrument was also administered individually to all subjects who had successfully completed the Piagetian-type test. Although there was no time limit for the Preconceived Knowledge Test, the average time required to complete the 14 items was from 15 to 25 minutes for both the elementary and secondary students. They were asked to predict the motion for common objects in 9 written questions (1 to 9) and 5 task (hands-on) questions (10-14). They were asked to explain their prediction of the anticipated motion and to give reasons for their answers; however, for purposes of analyzing the data, only correct responses were considered and no distinctions were made for ambiguous or fallacious reasons. This test was administered by this researcher; however, the answers were evaluated by the high school physics teacher and this researcher in order to normalize the qualitative interpretation of the answers.

Description of the Testing Instruments

Piagetian Test for Concrete Operationalism

This instrument was derived from Trojcak's (1979) article instructing teachers on the use and evaluation of Piagetian tests for determining intellectual devleopment. The Piagetian tasks selected to measure concrete operationalism were conservation tasks of number, using black and red checkers; of length, using two identical strips of colored paper; of substnace, using two different shapes of clay; of area, using two identical pieces of green paper and smaller squares to represent buildings; and of volume, using objects with equal volumes but different weights. The final task measured the students' ability to transform, using the falling pencil example represented in a series of pictures. Evaluations were based on the criteria and evaluation sheet provided in the Trojcak (1979) article. The evaluation of the test and the judgment regarding the operational level of the student were made by the person administering the test; however, several group discussions were held with the professional psychologist, following the collection of the data, in order to insure some minimum uniformity of evaluation. Only those fourth grade students who were able to complete the tasks for concrete operationalism were included in the study.

Piagetian Test for Formal Operationalism

This instrument was derived from studies done by Renner and Stafford (1972) testing the formal operational skills of high school and college students. The instrument included four written problems evaluating three separate but major intellectual structures. These included the separation and control of variables, combinational logic, and proportional reasoning. Proportional reasoning skills were examined using "The Shadows Incident" and "The Frogs Incident." Combinational logic was examined using the "Rock Incident"; the separation and control of variables was examined using the "Geranium Incident." Both of these questions required a separate scoring scale (Appendix A). The Piagetian task analysis scales used to measure the three intellectual structures mentioned were developed, tested, and validated by Renner, Prickett and Renner (1977) (Appendix A). These were administered and evaluated by this researcher in collaboration with the physics teacher and the professional psychologist. The evaluations were made using the Proportional Reasoning Scale, a technique similar to the Piagetian Interview Point

System (Inhelder & Piaget, 1958). Only those eleventh grade students who demonstrated formal operational skills were included in the study.

The Preconceived Knowledge Test

A purpose of this study was to develop a means to examine the nature of the preconceived knowledge concerning mechanical concepts of gifted and non-gifted students from two diverse age and intelligence groups. This instrument consisted of 9 written and 5 task questions dealing with the simple motion of common objects. These questions were derived from recent studies by McCloskey et al. (1980), Champagne et al. (1980b), Trowbridge and McDermott (1981), Viennot (1979), and Clement (1982). The 14 test items were chosen from a larger number of items pilot-tested with elementary and secondary students of a neighboring school system. The 14 test items of the present study were chosen after it was shown that fourth grade students were able to understand the questions and had some experience with the types of motion involved in order that both age groups could take the same test. The Preconceived Knowledge Test, as it was called, was administered individually to each subject by this researcher. This was done in a separate room and required approximately 15 to 25 minutes to complete. The subjects were asked to explain and justify their responses on each of the questions; however, for purposes of evaluating the data, the responses given were recorded as being either correct (1) or incorrect (0). The items were described in detail in Chapter 3 and a copy of the Preconceived Knowledge Test is included in Appendix B. The content validity for this instrument is based on recent studies using identical questions; a Kuder-Richardson (K-R20) reliability coefficient of .60584 was generated.

Method of Analysis

In order to compare the four sample groups with respect to their responses on the Preconceived Knowledge Test, the chi-square analysis was used. The data fit a 2 x 2 contingency table with one degree of freedom for each of the four analyses. Consequently, the Yates correction was utilized and significance was measured at the 1% level (Upton, 1978). The data resulting from the administration of the Preconceived Knowledge Test was in the form of correct (+1) or incorrect (0) for each of the subjects on all 14 test items. This was done, despite the fact that students were asked to explain and justify their responses, to give this researcher a feeling for the way the students were thinking and to make certain that they understood the questions. To test the stated hypotheses four separate chi-square analyses were carried out. These included comparisons between the gifted and non-gifted fourth grade subjects, the gifted and non-gifted eleventh grade subjects; and, in an attempt to measure the effect of age and intellectual development on preconceived knowledge, analyses were carried out comparing the gifted fourth with eleventh grade subjects and also the non-gifted fourth with the eleventh grade subjects. Based on the chi-square analysis of the data, significance was not achieved at the 1% level; consequently, the first null hypothesis dealing with preconceived knowledge vs. giftedness was not rejected for either the fourth or eleventh grade samples. The second null hypothesis dealing with preconceived knowledge vs. age and intellectual development was not rejected for the comparison with the non-gifted samples; however, for the gifted samples, the second null hypothesis was rejected for the task questions (10-14) but not rejected for the written questions (1-9). Within the limitations of this study, the analysis of the data suggests that gifted and non-gifted students experience similar difficulties when dealing with fundamental mechanical concepts, therefore suggesting that giftedness does not necessarily facilitate the understanding of basic mechanical principles. The comparisons between the fourth and eleventh grade samples did not produce a strong convincing argument for assuring significance between the two diverse age groups. Consequently, it was shown that students from diverse age and intellectual levels, as well as vastly different backgrounds in science training, experience many of the same difficulties when it comes to dealing with basic mechanical principles. These difficulties are rooted in a complex belief-system based on personal observations and experiences and is pre-Newtonian in form.

Implications for Science Educators

There are a number of implications of importance to science teachers and curriculum planners. The findings presented are generally supported by recent studies concerned with the role of preconceived knowledge of mechanical concepts in the learning of science. Much of the previous research in the 1960s and 1970s dealing with science education focused on the inquiry and discovery skills and the way these contributed to the enhancement of the learning environment.

Research into the area of preconceived knowledge of different scientific subjects offers a new and exciting consideration for science educators coping with the frustrations encountered in teaching scientific concepts. Piaget, over 30 years ago, pointed out that students learn from acting upon and manipulating their environment. This idea found its way into the curricular innovations of the 1960s and 1970s which promoted "inquiry" and "discovery" as the essence of science learning.

Recent studies on preconceived knowledge, including the present study, attempt to reach beyond the knowledge students acquire in the classroom setting. Instead, the shift in emphasis is to the knowledge that students bring with them to the classroom and the way this knowledge influences the learning process, whether the effects are negative or positive. Traditionally, science knowledge was measured by factually based tests or achievement tests where the central focus was on the science concepts and facts learned in the classroom. Recent studies show that despite a sizeable accumulation of scientific facts and concepts from classroom experiences students do not necessarily incorporate these into their personal belief-system. Studies show that, while students do give facts and concepts back to the teacher during exams and standardized tests, they rarely use this knowledge in dealing with everyday questions concerning basic mechanical principles.

The findings suggest that, despite the extensive testing utilized in the site district for identifying the gifted students, no significant difference was shown between these two groups for any of the questions on the

Preconceived Knowledge test. The educational community has come to expect higher grades and higher rank in class from gifted students as traditionally has been the case. The educational community accepts the basic tenet that intellectual ability and previous learning are among the best predictors of future learning and that IQ is still the best criterion for identifying giftedness. However, what is not clear is the degree to which this belief is true for different subject areas under different study conditions (Boulanger, 1981).

A study by Harty and Beall (1984) showed that higher achievement by gifted students may be more a function of positive attitudes towards gifted students than intelligence, since in some cases the non-gifted students with positive attitudes also demonstrated high achievement. A study by Ludlow and Woodrum (1982) showed that gifted students possess higher order cognitive skills, such as divergent thinking and problem-solving. However, the present study suggests this does not necessarily lead to the acceptance of a conceptual view which is in conflict with their own. The tentative findings of the present study show that gifted and non-gifted students share similar difficulties with basic mechanical principles. The implication is that, while gifted students may demonstrate higher levels of achievement in science courses, very little evidence exists to suggest that these students successfully incorporate knowledge from classroom experiences into their preconceived knowledge based on personal experiences outside the classroom. These results seem to be consistent with the findings of Boulanger (1981) and Sternberg (1984) who showed that measured ability based on IQ scores and other psychometric criterion, on the average, does not account for a noticeable variance in science learning. This suggests that, instead of trying to cover a textbook, the teacher's time would be better spent determining the quantity and quality of student-held views and the best method to expose the students to additional experience which facilitates the students bringing their views in line with the Newtonian view. In order for this reconciliation to be meaningful and permanent, the students must participate fully in the process.

Another major implication is derived from the analysis of data comparing the results on the Preconceived Knowledge Test of the fourth grade subjects with those of the eleventh grade. The eleventh grade subjects were currently taking a physics course and, as students in the science track at the site district, had received 7 additional years of science and mathematics instruction. Considering this major difference in age and amount of formal instruction, one might expect the older students to do appreciably better on the test; however, the analysis of the data does not support this expectation. On most of the 14 items, significance at the 1% level was not achieved. A close examination of Tables 3 and 4 in Chapter 4 shows that on several questions a larger percentage of the fourth grade sample answered correctly than did the eleventh grade. Admittedly, the number of subjects involved in the study is very small; however, the results suggest that students insist on clinging to their preconceived views concerning motion despite significant amounts of formal training in science. A further implication of these results is that additional training in science and greater intellectual maturity may serve either to solidify the preconceived views held by the students or not to contribute to dispelling them. In either case it seems that intellectual maturity and extensive training in science have little impact on the students' willingness to accept and to incorporate the Newtonian model of the world into their own.

An implication for those studying giftedness is that identification based solely on IQ scores is incomplete and that an expanded model of giftedness which somehow includes preconceived knowledge may be useful to science educators. Science educators and curriculum planners have long assumed that all scientific knowledge is based upon the foundation of Newtonian mechanics. The results of the study suggest, within its limitations, that even though Newtonian mechanics is fundamental to all science, the ideas are not necessarily easy to grasp or obvious. It is a sobering thought for science teachers in general and physics teachers in particular that the most fundamental and basic concepts of science become the source of major difficulty to students from diverse backgrounds, age, intellectual level, and training in science.

A further implication is that teachers may believe from test grades, course grades, and class rank that their students are indeed learning science. The students with higher IQ scores may also be better at memorizing the textbook version of Newtonian mechanics; however, the results of the present study show that, when students from diverse samples are confronted with questions dealing with basic mechanical concepts, these students ignore the textbook and classroom version in favor of their personally developed views, based on their experiences outside the classroom. These views are similar to the Aristotelian-Impetus model used during the Middle Ages; the student's intellectual development has little effect on these entrenched preconceived views held by the students. It appears that more "out of school" experiences of the older students only serve to stabilize their non-Newtonian views of the world.

This investigation, as well as other recent studies, demonstrates the need for a learning environment which acknowledges and confronts student-held views for the purpose of resolving the difference between the competing paradigms. It has been suggested that students develop their preconceived view of the world in much the same way science itself developed over the centuries (McCloskey, 1983). This may explain its Aristotelian-Impetus qualities and, therefore, should be respected for what it is, namely a model which is more reasonable, sensible, and plausible than the official textbook or classroom version. It should be remembered that scientists and intellectuals of Galileo's and Newton's time regarded these transformations as ridiculous and not consistent with what was believed tobe intuitively true and obvious from experience. This may explain why students avoid science on the high school level and begin to lose interest in science on the junior hgih school level; i.e., the classroom version of explaining natural phenomena may not make sense to the student.

It is not difficult to appreciate this enigma. Newton's Laws did not result exclusively from direct observations of motion but rather were generalized from several abstractions based on mathematical models. Newton was successful in formulating a coherent mathematical and geometric model which synthesized the laws of planetary motion of Kepler with the observations of Galileo. Known as the Law of Universal Gravitation, this synthesis is abstract, esoteric, and not obvious from the observation of ordinary objects. This may explain why natural philosophers were not able to deduce these natural laws from their observations of the simple motion of ordinary objects. How can one expect a student of any age or intellectual level to believe that an object set in motion will forever remain in motion? This is the essence of Newton's First Law of Motion; however, every ounce of common sense tells us an object set in motion eventually stops and no amount of formal and empirical proof will sway us from this belief. It is for this reason that the rational Aristotelian-Impetus model, successful for over 2,000 years, continues as the "sensible" explanation for experience with motion. Crombie (1959) argues that the great success of the Greek model is due to the fact that it brought explanation and prediction together, and this snythesis formed the crucial step in establishing the scientific movement. The studies cited throughout this paper suggest the Greek model, with its qualitative simplicity, continues in its usefulness as a model for understanding the world and as a basis for explaining experiences to others. Teachers and curriculum planners must reevaluate their attitudes towards students to include respect for their empirical knowledge as being complex, well-organized, and reasonable to the student, who must be looked upon as a serious learner, one who is developing a model by which he/she can hope to understand his/her experiences.

Suggestions for Further Research

The findings of the present study suggest a number of interesting directions for subsequent research into the nature of preconceived knowledge and its role in science learning. The presence of preconceived views concerning basic mechanics among diverse study samples, as was indicated in this study, characterizes the need to describe in greater detail these student-held views concerning mechanics and other scientific domains. Further research should seek to determine how and when these views develop in children, what information is gleaned from experiences with and observation of moving objects, and how they are processed in the intellectual formation of concepts. Psychologists should develop validated instruments for purposes of measuring levels of preconceived knowledge in science areas in order to standardize the evaluations.

The study did not examine preconceived knowledge of mechanics among eleventh grade subjects who were not taking physics concurrently or who were not on the science track of the site district. It might have been helpful to the study to see what differences, if any, in preconceived knowledge of mechanics exist between eleventh graders studying physics and those who are not. The study also did not examine this phenomenon for students from diverse socioeconomic backgrounds. Recent studies of intellectual traits, such as high IQ and achievement heretofore attributed to intelligence, have been shown to have a socioeconomic basis. A study by Harty and Beall (1984) showed that traits such as motivation, attitude, and self-esteem may contribute more to gifted behavior than IQ alone. For this reason it might have been useful to this study to examine preconceived knowledge among students from diverse socioeconomic groups. This is suggested as a basis for further study.

This research also did not examine differences in preconceived knowledge of mechanical concepts between maler and females. A study by Lawson (1975) showed that adolescent males and females exhibit differences in reasoning ability at different ages. Lawson's study demonstrated that males tend to perform significantly better than females on manipulative reasoning tasks and also on solving problems which require active restructuring of stimulus elements. Consequently, sex may play some role in the development of preconceived views of mechanics and is worthy of further investigation.

An area of educational research presently receiving a great deal of attention deals with developmental and cognitive psychology. The results of the present and other studies show that the Aristotelian-Impetus model for motion learned outside the classroom, probably during the preconcrete and concrete operational stages, serves the needs of students more effectively than the Newtonian version taught in the classroom. Cognitive psychologists have become interested in how and when this preconceived knowledge becomes a part of the students' conceptualized belief-system with which they explain the physical world. Lochhead (1978) and Champagne and Klopfer (1983) are working to elucidate the natural knowledge of physics which students bring to the classroom. Research into how children grow and learn is essential to this question. The findings of ths study suggest that the Piagetian stage of development reached by the students and the amount of formal science training received have very little effect on the misconceptions students hold concerning basic mechanical principles. Carter and Ormrod (1982) showed a positive relationship between certain types of cognitive development and age for gifted and non-gifted students. Their research suggests that any attempt at identifying giftedness should include a detailed description of the Piagetian stage of intellectual development achieved by the student. Additional research into the cognitive aspects of how and when children learn is essential to this question of how students develop preconceived views concerning the motion of objects in order to determine what classroom experiences contribute positively to the restructuring of children's ideas. Research by McCloskey (1983), Champagne et al. (1983b), Lochhead (1982) and the present study have shown that classroom experiences tend to reinforce the Aristotelian-Impetus view held by students rather than to restructure their thinking in line with the Newtonian view. This suggests that more research into how students acquire and use cognitive operations is needed.

Another area of research that has demonstrated some promise in dealing with misconceptions concerning motion held by students is computer-assisted instruction. Studies conducted by di Sessa (1982) and White (1984) have shown that when a computer is programed to illustrate motion according to Newton's Laws, the student can visually perceive the correct motion. Consequently, interacting with the computer and attempting different predictions based on the students' views hopefully will reconcile their preconceived views with the Newtonian. This is an exciting application of interactive dialogue with the computer and deserves further study.

One line of science education and psychological research of importance to science learning is the role of language and semantic memory. Piaget (1969) stated that logic was structured by language. Champagne et al. (1983a) and McDermott (1984) showed that many of the words used in physics with specific meanings have different generalized meanings in everyday usage. These include such terms as force, momentum, acceleration, speed, impetus, and inertia. Additional research is required to identify exactly how language is used to facilitate the conceptualization of scientific ideas and whether the use of words exclusively for purposes of scientific description might minimize the confusion caused by language.

The results of the present study showed no significance at the 1% level between gifted and non-gifted students on all questions of the Preconceived Knowledge Test; however, this lack of significance between the gifted and non-gifted must remain inconclusive and open for additional refined investigation. Further research is necessary using much larger and more diverse samples in order to determine consistency of these patterns and to make generalizations about these findings.

This study began by describing the practical relevance of an instructional problem of interest to this researcher, namely, student difficulties encountered in learning and believing in the laws of Newtonian mechanics. The studies cited in this dissertation have made it abundantly clear that these difficulties are linked to the fact that students coming into an introductory physics course have firmly embedded conceptualizations of how and why objects move. These conceptualizations are in clear conflict with the canonical view of the subject-matter domain which the student is required to learn. The main goal of every science teacher must be to confront the student's view of the world in order to increase comprehension of nature and not to stifle interest and curiosity as presently seems to be the case.

An interesting incident which occurred during the testing of the eleventh grade subjects underscores this issue. The task portion of the Preconceived Knowledge Test was being administered individually to the gifted subjects of the eleventh grade sample. The physics teacher had informed me earlier in the day that a student with superior academic credentials would be taking the test, and I was told she would do better than the other students. The basis for this confidence was her straight "A" average, her top position in the Junior Class and her high scores on the S.A.T.s. This researcher might have shared this confidence based on such superior academic credentials; however, the studies cited as part of this study were cause for skepticism. The physics teacher observed some of the students taking the task portion of the Preconceived Knowledge Test and happened to be in the back of the room when this particular student was completing the tasks.

The first question required the student to hold a heavy lead ball in one hand, a much lighter aluminum ball of equal size in the other hand, and to predict how they would fall if released together. This very intense and bright young lady held both objects about 2 feet above a box filled with sponge rubber and contemplated the question. She paused for a few moments and appeared puzzled over the apparently simple question. She looked at her physics teacher and looked at me and proceeded to explain what she had learned in class and read in the textbook; however, to our surprise and in an apologetic tone, she explained that the heavy ball would fall faster and strike the box before the aluminum ball because of its additional weight. She recalled a picture in the textbook showing objects of different weights falling together; however, she decided to go with her intuitive feelings on the question. She was asked to release the objects together, and to her surprise they hit the box simultaneously. Unsure of her observation she again raised the objects, and dropped them together; again they hit simultaneously. This time, more sure of her observation, she looked at her physics teacher and said, "I guess you were right, but it still doesn't seem possible." The cognitive dissonance experienced by this bright young lady was obvious to her physics teacher and to this researcher. Similar reactions were evident from other students to a greater or lesser degree, especially with the eleventh grade subjects; however, the example cited is especially interesting because of her superior academic record. This suggests that Newtonian physics is remote and unconvincing even to an excellent student earning straight "A's" in physics. The Newtonian model does not seem to be useful to students in explaining their experiences or in answering their questions.

Why does a model which scientists discarded over 300 years ago serve students so adequately in understanding their world and in what manner do they come to hold these views? The Aristotelian-Impetus model holds that the properties of motion are imparted to the body and influence its motion until they are dissipated when the object returns to its natural state of rest. Evidently this view is more in line with the everyday observation of common objects than is the formal, empirical model of Newton.

Science educators must come to know and appreciate the Aristotelian-Impetus model of motion in order to meet the students at their level of understanding of mechanical concepts. Thus, the students can learn to use their preconceived views to evaluate alternative views of motion. Holton (1973) suggests that the growth of imagination in a student recapitulates the growth of scientific thinking. Therefore, students should be presented with the Newtonian and Galilean models as an aid in developing their intuitions and in bridging the gap between their natural Aristotelian-Impetus bent and the strange, new concepts of modern physics.

The Aristotelian-Impetus perspective on motion, with which most students naturally feel comfortable, closely resembles the model utilized by scientists and philosophers from the Greek period well into the 18th century. Apparently the Greeks formulated a model for dealing with physical realities which persists even to the present. Greek concepts of human emotion, literature, theater, language and politics are present everywhere in modern cultures throughout the Western World and continue to exert a great influence on thinking in these areas. Consequently, it should be no surprise that the Greek concept of the physical world holds universal appeal to the rational and inquisitive minds of present-day students. The cultural persistence of the Greek concepts is a testimony to their viability in describing physical realities. This may explain, in part, why the Aristotelian-Impetus model for describing motion continues to be a useful possibility for understanding the observed world.

The educational community, from the elementary to the college levels, has tended to ignore the importance of preconceived knowledge in the learning of science and the confusion caused by these competing paradigms. Present methods of teaching assume that students are like empty computers, then proceed to load the students with facts and figures and expect them to process correctly this information on command. The reality is that students come to the classroom with a mind already programmed to understand motion which is based on a tremendous amount of raw data gained from personal experiences. It is futile to expect a student to ignore or suspend his/her preconceived views and to accept, without reservation, the Newtonian models solely on the basis of authority. It appears that science educators have confused science teaching with the discipline of science. Science has mistakenly been assumed to represent factual information with the role of the science teacher that of a facilitator between the student and this body of factual knowledge. Einstein (1938), remembering the rigid and rote learning of German authoritarian schools, warned that science is not a collection of laws and unrelated facts but rather a creation of the human mind with its freely invented ideas and concepts used to make sense of sensory observations. The science-education community would do well to de-emphasize the importance of covering certain prescribed information, whether it be from a textbook or a curriculum guide, in favor of evaluating the levels of preconceived knowledge held by the students. In this way, confidence in the Newtonian model could be developed as an alternative means of understanding motion.

Teachers must assume a greater role in resisting the pressures of a hierarchical educational system which expects a superficial treatment of scientific concepts and the presentation of a certain minimal amount of factual information. Despite the pressures of overcrowded classrooms and heavy teaching schedules, efforts must be made to utilize some of the time in personally confronting the preconceived views held by the students which act as an impediment to the teaching and learning of science. The Socratic dialectic method of questioning students and forcing them to articulate their beliefs about the physical world should go a long way in bringing the Aristotelian-Impetus model to the forefront of the educational process, in creating a cognitive dissonance with the presentation of the Newtonian model and hopefully in resolving the conflicting paradigms. The teacher must be the Socratic gadfly probing the students' beliefs and forcing them to explain and justify their views of the world. In this way, understanding of concepts will transcend matters of content. The call for this understanding in science learning and an emphasis on the holistic and humanistic aspects are not new. Einstein (1938) stated that the aim of every physical theory is to understand personal observations and to make a logical connection between these observed facts and a theoretical concept of reality. Einstein also stated, as did Bronowski (1973) and Weisskopf (1976), that a personal belief in the harmony of the world and the ability to grasp this harmony remains the fundamental motive for all sciences. However, the means of grasping this harmony is not always intuitive, for the laws of nature are subtle and elusive; experience has shown that obvious intuitive explanations are often incorrect (Einstein & Infeld, 1938). Schrodinger (1957), a pioneer in the development of wave mechanics, indicated that the laws of physics are not the paradigm of exactitude they were thought to be but rather an attempt by man to explain as many of his observations as possible with the fewest number of concepts. Schrodinger and Weisskopf, like Einstein, saw science not as a collection of equations and facts but rather a totally humanistic approach to understanding nature. The world of experience, so crucial to the young developing mind, can hamper the work of the theoretical physicist (Nelson, 1985). Einstein (1923) said the theoretical physicist, like the poet, painter and philosopher, overcomes the world of experience by replacing it to some extent with a simplified and lucid image of the world. The scientist, according to Einstein, is seeking a peace and serenity he cannot find within "the narrow confines of swirling personal experience." This vigorous and precise view of the world, describing all its interrelationships, is satisfying to the theoretical physicist working with the uncertainties and probabilities governing the world of the atom; however, he must, according to Einstein, still work with those ideas and concepts accessible to experience. Even the theoretical physicist must return to the world of experience, for it is from this world of personal experiences that we develop our view of the physical world. This is as true for a theoretical physicist studying the forces holding the nucleus together as it is for a young child watching a ball thrown up in the air. It is through this window of personal experience that we first see how the world functions, and on these observations we build our personal conceptions of the world. These views must be identified, their strengths measured, and their existence incorporated into the learning process. Only in this way can students eventually adopt the Newtonian view as their own and incorporate it into their personal belief system. We must believe that students, if given the opportunity and reason, will adopt a Newtonian model for motion. Albert Einstein once said, "The most incomprehensible fact of nature is the fact that nature IS comprehensible."

APPENDIX A

INTERPRETATION OF PIAGETIAN-TYPE TASK INTERVIEWS FOR CONCRETE-OPERATIONAL TRAITS

CHILD ________________________________ AGE ________________

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1. This child demonstrated conservation of ______ number, ______ substances, ______ length, ______ area, ______ weight, ______ volume. (Check the tasks which were performed logically.)

2. The state of transformation was recognized in the falling pencil task. ______

3. The child exhibited the following:

PREOPERATIONAL TRAITS	CONCRETE-OPERATIONAL TRAITS

4. The rank order (first to last) of reaction types was:

______ random, ______ romancing, ______ suggested

______ liberating, ______ spontaneous.

5. The child's intellectual stage of development seems to be:

______ Preoperational (no conservation)

______ Low transitional into concrete-operational (conserved one or two concepts)

______ Beginning concrete-operational (conserved three to four concepts)

______ Concrete-operational (conserved all but volume; succeeded with transformation)

______ Transitional toward formal-operational (justified all tasks correctly).

FOUR PIAGETIAN TASKS USED TO DETERMINE FORMAL REASONING ABILITY (Renner, J., 1978)

1. The lengths of a shadow of a building and the shadow of a post are measured at the same time of day.

   The building shadow's length is 50 meters.

   The height of the post is 3 meters.

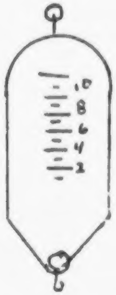
   The post shadow's length is 2 meters.

   How many meters tall is the building? Show you calculations. Write a paragraph to explain why you computed the height of the building the way you did.

2. An ecologist conducted an experiment to find out how many frogs lived in a pond. He could not catch all the frogs and count them. The first day he caught 55 frogs and put a band on one of the legs of each frog. He waited a week to give the banded frogs a chance to distribute themselves evenly throughout the pond. He then caught 72 frogs, and 12 of them had bands on one leg.

   Using all of this information, what could the ecologist conclude about the number of frogs in the pond. Show any calculations you make, and then write a paragraph to explain how you arrived at your answer.

3. You have an unlimited supply of geranium plants. They are exactly alike. All are in the same kind of pots and have been planted in the same kind of soil. You are told that such factors as fertilizer, the amount of water, and the amount of sunlight affect the way the plants will grow. Describe the experiments you need to do in order to test whether or not each of those factors is important to the growth of geranium plants. Be sure to include reasons why you do the experiment the way you do.



4. A string is tied around a rock and placed on a table. The hook of the spring scale is lifted and the rock is held above the table. The scale shows a reading of eight (8) pounds. The rock is kept attached to the scale and placed in a container of water. The rock is lowered into the water enough so it is completely covered. The rock does not touch the sides or bottom of the container. The scale now shows a reading of six (6) pounds.

Write a paragraph that explains why the scale readings are different. Perhaps you think that two different scale readings are not possible. If you do, write a paragraph which explains why you believe as you do.

SCORING SCALE USED TO EVALUATE PIAGETIAN FORMAL REASONING TASKS

Proportional Reasoning Scale (Shadow and Frog Incidents)

NAME		
Point Value	Response	Check
1.	no response -- don't know	
2.	confused attempt to explain	
3.	realizes subsets and grasps relationships	
4.	uses ratios but incorrectly	
5.	goes beyond ratios but still can't solve the problems	
6.	use of proportions and correct logic to solve correctly	
7.	correct solution with relevant discussion	

Separation and Control of Variables
(The Geranium Incident)

NAME		
Point Value	Response	Check
1.	no response -- don't know	
2.	reaction but uses irrelevant procedures	
3.	description of conditions--appreciates cause and effect	
4.	attempts to control quantity of variables	
5.	valid control of at least one variable	
6.	quantitative control of all variables	
7.	correct control of all variables with appropriate explanations	

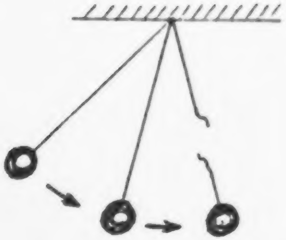
Combinatorial Logic Scale (Rock and Scale Incident)

NAME		
Point Value	Response	Check
1.	no response -- don't know	
2.	confusion or rejection of the problem	
3.	combines data to form incorrect inferences	
4.	recognizes that the weight is affected by the water	
5.	correctly explains how displacement in water causes a difference in the scale readings	

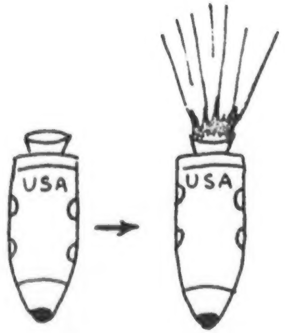
APPENDIX B

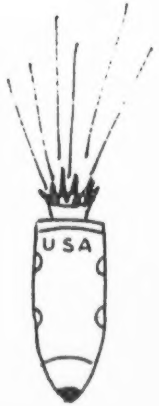
Preconceived Knowledge Test

Question #1

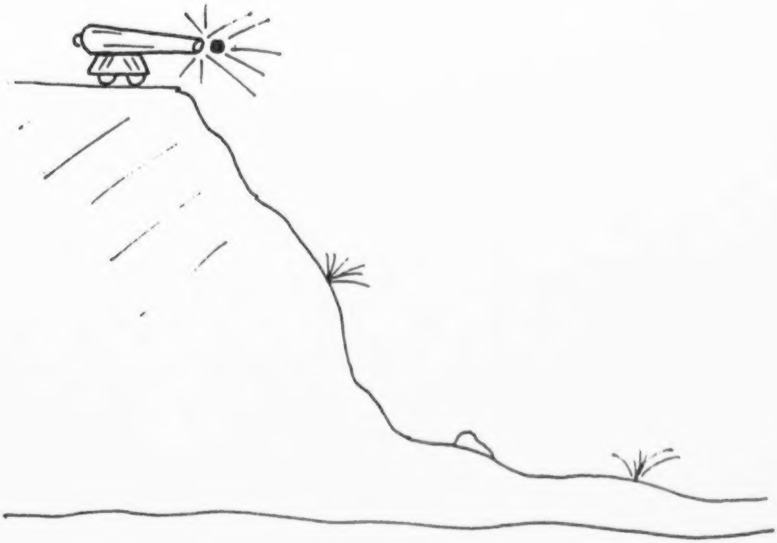


Question #2

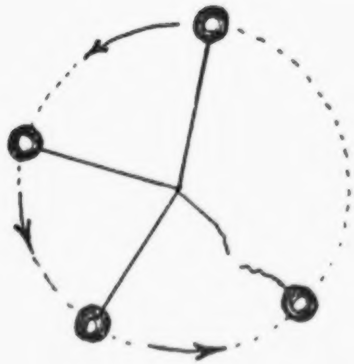




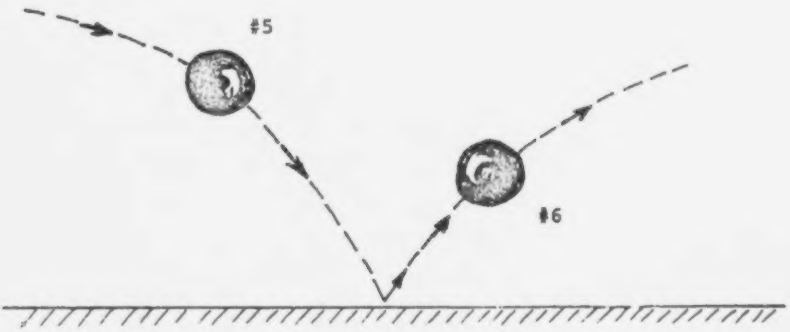
Question #3



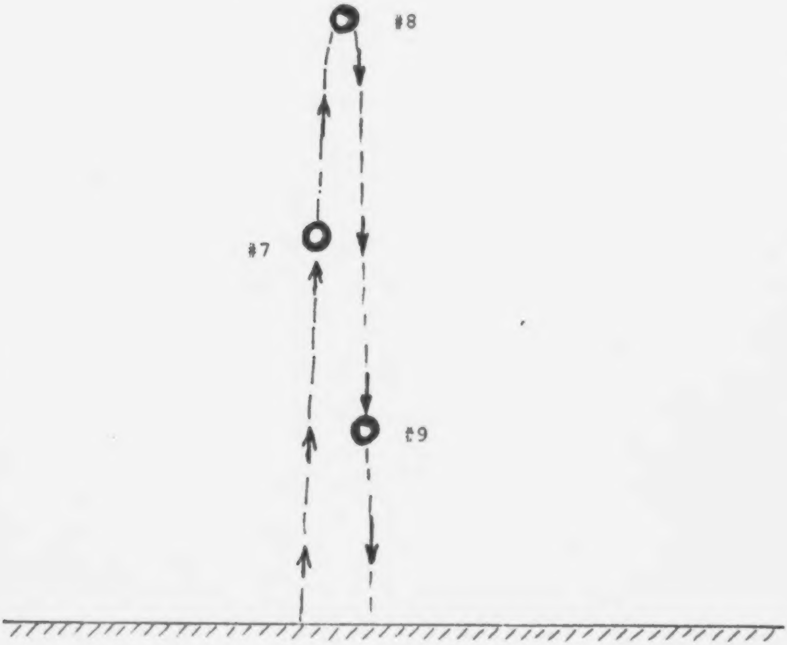
Question #4



Questions #5 and #6

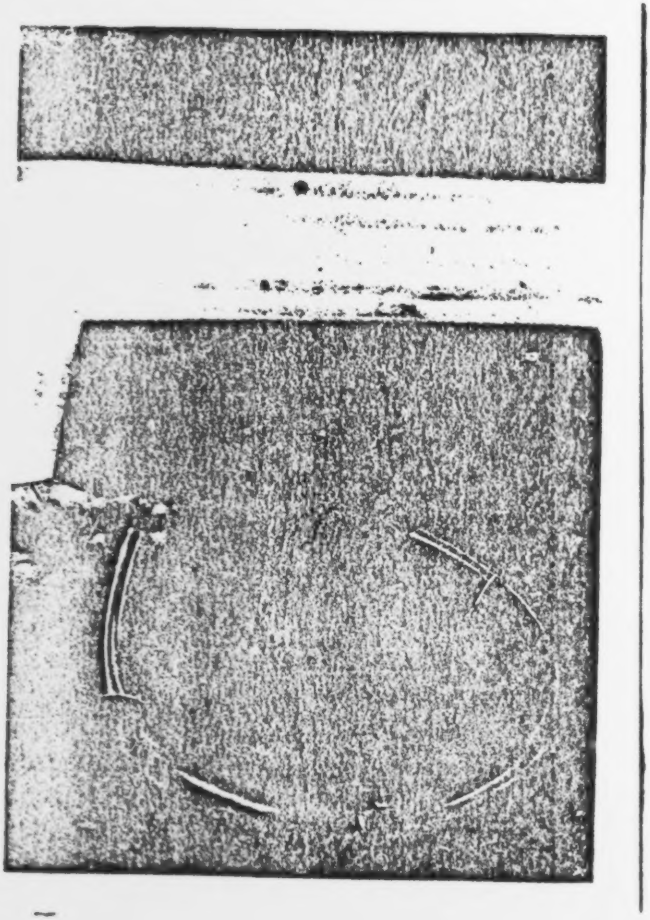


Questions #7, 8, and 9



Question #10

Question #11



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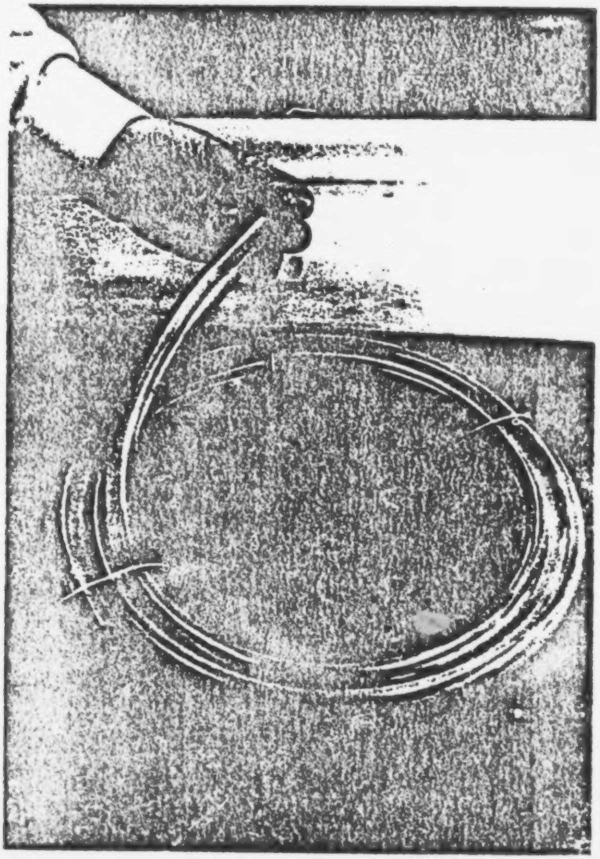
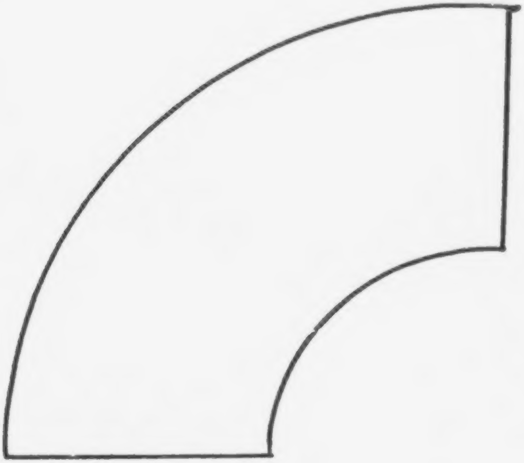
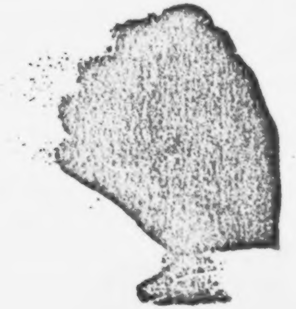


Question #13





Question #14

BIBLIOGRAPHY

Abraham, W. (1958). *Common sense about gifted children*. New York: Harper and Row.

Albert, E. (1979). Can Ausubel's theory of meaningful learning become an alternative to Piagetian psychology? *Science Education*, *63*(1): 135-138.

Alexander, P., & Muia, J.A. (1980). Gifted reading programs: Uncovering the hidden potential. *Reading Horizons*, *20*, 302-310.

American Association for the Advancement of Science. (1975). *Science: A process approach*. Lexington, MA: Ginn.

Anderson, R.D. (1965). Children's ability to formulate mental models to explain natural phenomena. *Journal of Research in Science Teaching*, *3*, 326-332.

Anderson, R.C., Spiro, R.J., & Montage, W.E. (Eds.). (1977). *Schooling and the acquisition of knowledge* (pp. 415-431). Hillsdale, NJ: Erlbaum.

Aristotle. (1812). *Questions on mechanics*. Van Cappelle, Ed. Amsterdam.

Arons, A.B. (1976). Cultivating the capacity for formal reasoning: Objectives and procedures in the introductory physical science course. *American Journal of Physics*, *44*(9): 834-838.

Association of American Colleges & American Association for the Advancement of Science (1982). *Science and technology education for civic and professional life: The undergraduate years*. A Report of the Wingspread Conference, June 1-3, Wingspread Conference Center, Racine, Wisconsin.

Ausubel, D.P. (1963). *The psychology of meaningful verbal learning*. New York: Grune and Stratton.

Ausubel, D.P. (1968). *Educational psychology: A cognitive view*. New York: Holt, Rinehart and Winston, Inc.

Ausubel, D.P., Novak, J.D., & Hanesian, H. (1978). *Educa-*

tional psychology: A cognitive view (2nd ed.). New York: Holt, Rinehart and Winston.

Bacon, R. (1928). Opus Magus (R. Burke, Trans.). Philadelphia, PA: University of Pennsylvania Press. (Original work published 1620)

Bandura, A. (1977). Social learning theory. Englewood Cliffs, NJ: Prentice-Hall.

Bandura, A. (1982). Self-efficacy mechanism in human agency. American Psychologist, 37, 122-147.

Barnes, G. (1977). Scores on a Piaget-type questionnaire versus semester grades for lower-division college physics students. American Journal of Physics, 44, 841-847.

Bass, J.E., & Maddux, C.D. (1982). Scientific explanations and Piagetian operational levels. Journal of Research in Science Teaching, 19(7): 533-541.

Bell, B.F. (1981). When is an animal not an animal? Journal of Biology Education, 15, 3.

Berenson, M.L., Levine, D.M., & Goldstein, M. (1983). Intermediate statistical methods and applications: A computer package approach. Englewood Cliffs, NJ: Prentice-Hall.

Biehler, R., & Snowman, J. (1982). Psychology applied to teaching. Boston: Houghton Mifflin Company.

Bigge, M., & Hunt, M. (1980). Psychological foundations of education. New York: Harper & Row Publishers.

Bloom, B.S. (1976). Human characteristics and school learning. New York: McGraw Hill.

Boulanger, F.D. (1981). Ability and science learning. Journal of Research in Science Teaching, 18(2): 113-121.

Boulanger, F.D., & Kremer, B.K. (1981, July). Age and developmental level as antecedents of science learning. Journal of Research in Science Teaching, 18(4): 371-384.

Bransford, J.D. (1979). Human cognition. Belmont, CA: Wadsworth.

Bransford, J.D., & McCarrell, N.S. (1974). A sketch of a cognitive approach to comprehension. In W.B. Weimer & D.S. Palermo (Eds.), *Cognition and the symbolic processes*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Bronowski, J. (1973). *The ascent of man*. Boston: Little, Brown & Company.

Brown, F.G. (1976). *Principles of educational and psychological testing* (2nd ed.). New York: Holt Rinehart and Winston.

Brumby, M.N. (1982). Students' perceptions of the concept of life. *Science Education*, *66*, 613-622.

Bruner, J.S. (1956). *A study of thinking*. New York: Wiley.

Bruner, J.S. (1960). *The process of education*. New York: Vintage Books, Random House.

Bruner, J.S. (1971). *The relevance of education*. New York: Norton.

Butterfield, H. (1965). *The origins of modern science, 1300-1800*. New York: Free Press.

Caramazza, A., McCloskey, M., & Green, B. (1981). Naive beliefs in "sophisticated" subjects: Misconceptions about trajectories of objects. *Cognition*, *9*, 117-123.

Carroll, J.B. (1978). How shall we study individual differences in cognitive abilities? Methodological and theoretical perspectives. *Intelligence*, *2*, 87-115.

Carter, K.R., & Ormrod, J.E. (1982). Acquisition of formal operations by intellectually gifted children. *Gifted Child Quarterly*, *26*(3): 110-115.

Cattell, J.M. (1915). Families of American men of science. *Popular Science Monthly*, *86*, 504-515.

Champagne, A.B., Hoz, R., & Klopfer, L.E. (1983). *Construct validation of the cognitive structure of science concepts*. Pittsburgh, PA: University of Pittsburgh, Learning Research and Development Center.

Champagne, A.B., & Klopfer, L.E. (1977). A sixty-year perspective on three issues in science education. *Science Education*, *61*, 437-446.

Champagne, A.B., & Klopfer, L.E. (1980a). *Differential effects of students' science knowledge and processing skills in solving verbal problems*. Pittsburgh, PA: University of Pittsburgh, Learning Research and Development Center.

Champagne, A.B., & Klopfer, L.E. (1980b). *Using the ConSAT: A memo to teachers*. Pittsburgh, PA: University of Pittsburgh, Learning Research and Development Center.

Champagne, A.B., & Klopfer, L.E. (1981). Structure, process skills and the solution of verbal problems involving science concepts. *Science Education*, *65*(5): 493-511.

Champagne, A.B., & Klopfer, L.E. (1982). A causal model of students' achievement in a college physics course. *Journal of Research in Science Teaching*, *19*, 299-309.

Champagne, A.B., & Klopfer, L.E. (1983, January). *Naive knowledge and science learning*. Paper presented at the annual meeting of the American Association of Physics Teachers.

Champagne, A.B., Klopfer, L.E., & Anderson, J.H. (1980). Factors influencing the learning of classical mechanics. *American Journal of Physics*, *48*, 1074-1079.

Champagne, A.B., Klopfer, L.E., & Gunstone, R.F. (1980). *A model of adolescent's understanding of physical phenomena and its application to instruction*. Pittsburgh, PA: University of Pittsburgh, Learning Research and Development Center.

Champagne, A.B., Klopfer, L.E., & Gunstone, R.F. (1982). Cognitive research and the design of science instruction. *Educational Psychologist*, *17*(1): 31-53.

Champagne, A.B., Klopfer, L.E., Solomon, C.A., & Cahn, A.D. (1980). *Interaction of student's knowledge with the comprehension and design of science experiments*. Unpublished manuscript. Pittsburgh, PA: University of Pittsburgh.

Chiappetta, E.L. (1976). A review of Piagetian studies relevant to science instruction at the secondary and college level. *Science Education*,*60*(2): 253-261.

Chomsky, C. (1969). *The acquisition of syntax in children from 5-10*. Cambridge, MA: M.I.T. Press.

Chomsky, N. (1968). Language and mind. New York: Harcourt, Brace & Janovich.

Clagett, M. (1959). The science of mechanics in the middle ages. Madison, WI: University of Wisconsin Press.

Clement, J. (1977). Catalog of students' conceptual models in physics (Working Paper). Amherst: University of Massachusetts, Department of Physics and Astronomy.

Clement, J. (1982). Students' preconceptions in introductory mechanics. American Journal of Physics, 50, 66-71.

Clement, J., & Brown, D. (1983). Using analogical reasoning to deal with "deep" misconceptions in physics (Working Paper). Amherst: University of Massachusetts.

Cohen, H.D., Hillman, D.F., & Agne, R.M. (1978). Cognitive level of college physics achievement. American Journal of Physics, 46(10): 1026-1029.

College Entrance Examination Board. (1977). On further examinations: Report of the advisory panel on scholastic aptitude test score decline. New York: College Entrance Examination Board.

Craik, F.I.M., & Lockhart, R.S. (1972). Levels of processing: A framework for memory research. Journal of Verbal Learning and Verbal Behavior, 11, 671-684.

Crombie, A.C. (1959). Medieval and early modern science, vol. 1. New York: Doubleday and Co.

D'Amour, G. (1979). Problem-solving strategies and the epistemology of science. In J. Lochhead & J. Clement (Eds.), Cognitive process instruction. Philadelphia, PA: The Franklin Institute Press.

Davidson, J.E., & Sternberg, R.J. (1984). The role of insight in intellectual giftedness. Gifted Child Quarterly, 28(2): 58-64.

DeCarcer, J.A., Gabel, D.L., & Staver, J.R. (1978). Implications of Piagetian research for high school science teaching: A review of the literature. Science Education, 64(4): 571-583.

Delisle, J.R., & Renzulli, J.S. (1982). The revolving door identification and programming model: Correlates of creative production. Gifted Child Quarterly, 26(2).

Dewey, J. (1916). Democracy and education. New York: MacMillan.

Dijksterhuis, E.J. (1961). The mechanization of the world picture. London and New York: Oxford University Press.

diSessa, A. (1982). Unlearning Aristotelian physics: A study of knowledge-based learning. Cognitive Science, 6, 37.

Donaldson, M. (1979). The mismatch between school and children's minds. Human Nature.

Driver, R. (1973). The representation of conceptual frameworks in young adolescent science students. Doctoral dissertation, University of Illinois, Urbana-Champaign, ILL.

Driver, R., & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. Studies in Science Education, 5, 61-84.

Duckworth, E. (1974). The having of wonderful ideas: Piaget in the classroom [E. Schewebel and J. Ralph (Eds.)]. London: Routledge & Kegan Paul.

Eanet, M.G. (1981). Cognitive process instructions: New approaches to learning in science. Paper presented at the Second Annual Meeting of the American Reading Forum, Sarasota, Florida. (December)

Eddington, A.S. (1928). The nature of the physical world. New York: Macmillan.

Educating Americans for the 21st century. (1983, September). A Report to the American People and the National Science Board by the National Science Board Commission on Precollege Education in Mathematics, Science and Technology. Washington, DC: National Science Foundation.

Einstein, A. (1905). On the electrodynamics of moving bodies. Annuals of Physics, 4F, 17.

Einstein, A. (1953). *Substance and function: Theory of relativity* (E. Cassirer, Ed.). New York: Dover Publications. (Original work published 1923)

Einstein, A., & Infeld, L. (1938). *The evolution of physics*. New York: Simon and Schuster.

Elyon, B., & Reif, F. (1979). *Effects of internal knowledge organization on task performance* [Technical Report]. Berkeley, CA: University of California, Group in Science and Mathematical Education.

Erickson, G.L. (1979). Children's conceptions of heat and temperature. *Science Education*, *63*(2): 221-230.

Eylon, B.B. (1980). Effects of knowledge organization on task performance (Doctoral dissertation, University of California at Berkeley, 1979). *Dissertation Abstracts International*, *40* (7), 3923-A.

Feigel, H., & Brobeck, M. (Eds.). (1953). *Readings in the philosophy of science*. New York: Appleton-Century-Croft.

Fensham, P.J. (1980). A research base for new objectives of science teaching. *Research in Science Education*, *10*, 224-227.

Ferguson, G.A. (1966). *Statistical analysis in psychology and education*. New York: McGraw Hill.

Feynman, R.B. (1963). *The Feynman lectures on physics*, vol. 1. Reading, MA: Addison-Wesley, 1963.

Fleshner, E.A. (1963). The mastery of children of some concepts in physics. In Simon & Simon (Eds.), *Educational psychology in the USSR*. Boston: Routledge & Kegan.

Freedman, J.L. (1978). *Introductory psychology*. Reading, MA: Addison-Wesley Publishing Co.

French, A.P. (1971). *Newtonian mechanics* (2nd ed.). New York: W.W. Norton & Co., Inc.

Freyberg, P.S., & Osborne, R.J. (1981). *Who structures the curriculum: Teacher or learner?* [SET 2, Item 6]. New Zealand: New Zealand Council for Educational Research.

Fuller, R.G., Karplus, R., & Lawson, A. (1977). The ADAPT book. Lincoln: University of Nebraska, ADAPT Program.

Gage, N.L., & Berliner, D. (1984). Educational psychology (3rd ed.). Boston: Houghton Mifflin.

Gagné, R.M. (1963). The learning requirements for inquiry. Journal of Research in Science Teaching, 9(1): 144-153.

Gagné, R.M. (1968). Learning hierarchies. Educational Psychology, 6, 1-9.

Gagné, R.M. (1970). Conditions of learning (2nd ed.). New York: Holt, Rinehart and Winston.

Gagné, R.M. (1980). Preparing the learner for new learning. Theory into Practice, 19, 6-9.

Galilei, G. (1914). Dialogues concerning the two new sciences [H. Crew & A. de Salvio, Trans.]. New York: Dover Publications. (Original work published 1590)

Galilei, G. (1953). Dialogues concerning the two chief world systems [S. Drake, Tran.]. Berkeley: University of California. (Original work published 1632)

Galton, F. (1869). Hereditary genius. London: MacMillan & Co.

Gamow, G. (1961). Biography of physics. New York: Harper & Row.

Getzels, J., & Jackson, P. (1962). Creativity and intelligence. New York: J. Wiley & Sons.

Gilbert, J.K., Osborne, R.J., & Fensham, P.J. (1982). Children's science and its consequences for teaching. Science Education, 66(4): 623-633.

Glass, A.L., Holyoak, K.J., & Santa, J.L. (1979). Cognition. Reading, MA: Addison-Wesley.

Glass, B. (1961). A new high school biology program. American Scientist, 49(12): 526.

Good, R.G. (1977). How children learn science. New York: MacMillan Publishing Company.

Green, B., McCloskey, M., & Caramazza, A. (1980). Curvilinear motion in the absence of external forces: Naive beliefs about the motion of objects. Science, 210, 1139-1141.

Greeno, J.G. (1980). Some examples of cognitive task analysis with instructional implications. In R.E. Snow, P.A. Federico, & W.E. Montague (Eds.), Aptitude, learning and instruction, vol. 2. Hillsdale, NJ: Erlbaum.

Guilford, J.P. (1959). Traits in creativity. In H.H. Anderson (Ed.), Creativity and its cultivation. New York: Harper and Row.

Guilford, J.P. (1967). The nature of human intelligence. New York: McGraw Hill.

Guthrie, E.R. (1952). The psychology of learning (rev. ed.). New York: Harper and Row.

Halliday, D., & Resnick, R. (1981). Fundamentals of physics (2nd. ed.). New York: John Wiley & Sons.

Harty, H., & Beall, D. (1984). Attitudes toward science of gifted and non-gifted fifth graders. In National Association for Research in Science Teaching.

Havighurst, R. (1953). Developmental tasks and education. New York: Longmans, Green.

Hawkins, D. (1965). Messing about in science. Science & Children, 5, 5-9.

Head, J.O., & Sutton, C.R. (1981, April). Structures of understanding and the ontogensis of commitment. Paper presented at A.E.R.A., Los Angeles, CA.

Hebb, D.O. (1949). The organization of behavior. New York: Wiley.

Helgeson, S.L. (1974, December). Impact of the National Foundation Teacher Institute Program [Research Paper No. 16]. Minneapolis: University of Minnesota, Minnesota Research and Evaluation Project.

Helgeson, S. (1978). Priorities for research in science education: An introduction. Journal of Research in Science Teaching, 15, 95-97.

Herron, J.D. (1978). Role of learning and development: Critique of Novak's comparison of Ausubel and Piaget. Science Education, 62, 593-605.

Hewson, M.G., & Hewson, P.W. (1983). Effect of instruction using students' prior knowledge and conceptual change strategies on science learning. Journal of Research in Science Teaching, 20(8): 731-743.

Hewson, P.W. (1980, April). A case study of the effect of metaphysical commitments on the learning of a complex scientific theory. Paper presented at the American Educational Research Association (AERA).

Hewson, P.W. (1981). A conceptual change approach to learning science. European Journal of Science Education, 3, 383-396.

Hilgard, J.R. (1932). Learning and maturation in preschool children. Journal of Genetic Psychology, 42, 40-53.

Holton, G. (1973). Thematic origins of scientific thought: Kepler to Einstein. Cambridge, MA: Harvard University Press.

Horn, J.G., & James R.K. (1978, November). Where are we in elementary science education? Paper presented at the National Meeting of School Science and Mathematics Association, Des Moines, IA.

Hull, C.L. (1943). Principles of behavior: A introduction to behavior therapy. New York: D. Appleton.

Hunt, J. (1961). Intelligence and experience. New York: The Ronald Press Co.

Hurd, P.O. (1970). New curriculum perspectives for junior high school science. Belmont, CA: Wadsworth Publishing Co.

Hurd, P.O., & Gallagher, J.J. (1968). New directions in elementary science teaching. Belmont, CA: Wadsworth Publishing Co.

Inhelder, B. (1953). Criteria of the stages of mental development. In J. Tanner & B. Inhelder (Eds.), Discussions on child development. New York: International University Press.

Inhelder, B. (1972). Information processing tendencies in recent experiments in cognitive learning. Philadelphia, PA: Jean Piaget Society.

Inhelder, B., & Piaget, J. (1958). The growth of logical thinking from childhood to adolescence. New York: Basic Books.

Inhelder, B., & Piaget, J. (1969). The early growth of logic in the child. New York: R. Norton Library.

Isaac, S., & Michael, W.B. (1982). Handbook in research and evaluation for education and the behavioral sciences. San Diego,CA: EdITS Publishers.

Jaki, S.L. (1969). Goethe and the physicists. American Journal of Physics, 37, 195-203.

Jensen, A.R. (1980). Bias in mental testing. New York: Free Press.

Johnson, P.E. (1964). Associative meaning of concepts in physics. Journal of Educational Psychology, 55, 84-88.

Jones, H.L., & Russell, M.J. (1979). Hierarchical learning paradigm. Journal of Research in Science Teaching, 16(6).

Joyce, B. (1979). Toward a theory of information processing in teaching. Educational Research Quarterly, 3, 66-77.

Judd, C.H. (1915). Psychology of high school subjects. Boston: Ginn & Co.

Juraschek, W.F. (1974). The performance of prospective teachers on certain Piagetian tasks. Unpublished doctoral dissertation, University of Texas at Austin.

Kaiser, M.K., McCloskey, M., & Proffitt, D.R. (1984). Development of intuitive theories of motions: Curvilinear motion in the absence of external forces. Baltimore, MD: Johns Hopkins University. (Unpublished Report: McCloskey)

Karplus, R. (1974). The science curriculum improvement study. Berkeley, CA: University of California.

Karplus, R. (1981). Educational aspects of the structure of physics. American Journal of Physics, 49(3): 238-241.

Karplus, R., Lawson, A.E., Wollman, W., Appel, M., Bernoff, R., Howe, A., Rusche, J.J., & Sullivan, F. (1977). Science teaching and the development of reasoning of thought. Berkeley, CA: University of California.

Karplus, R., & Thier, H.D. (1978). A new look at elementary school science. Chicago: Rand McNally & Co.

Kelly, G.A. (1969). Ontological acceleration. In B. Maher (Ed.), Clinical psychology and personality: The selected papers of George Kelly. New York: Wiley & Son, Inc.

Klein, S.E., President. (1982). National Science Teachers Association Testimony presented to the U.S. Senate Sub-committee on N.S.F. funding.

Koestler, A. (1976). The vision that links the poet, the painter, and the scientist. The Times, 25, 8.

Kohlberg, L. (1969). Stage and sequence: The cognitive-development approach to socialization. In Handbook of socialization theory and research. New York: Rand McNally.

Kolody, G.A. (1977). How students learn velocity and acceleration. Journal of College Science Teaching, 6, 224-227.

Kuhn, T.S. (1962). The structure of scientific revolutions. Chicago, IL: University of Chicago Press.

Kuslan, L.I., & Stone, A.H. (1969). Readings on teaching children's science. Belmont, CA: Wadsworth Publishing Co.

Lammers, T.J. (1955). Elementary school yearbook in the past century. Science Teacher, 24(4): 11-14.

Larkin, J. (1981). Cognition of learning physics. American Journal of Physics, 49(6): 534-541.

Larkin, J., McDermott, J., Simon. D.P., & Simon, H.A. (1980). Expert and novice performance in solving physics problems. Science, 210, 1139-1141.

Lawson, A.E. (1975). Sex difference in concrete and formal reasoning ability as measured by manipulative tasks and written tasks. Science Education, 59(3): 397-405.

Lawson, A.E. (1978). The development and validation of a classroom test of formal reasoning. Journal of Research in Science Teaching, 15(1).

Lawson, A.E. (1979). The developmental learning paradigm. Journal of Research in Science Teaching, 16(6): 501-515.

Lawson, A.E., & Karplus, R. (1977). Should theoretical concepts be taught before formal operations? Science Education, 6, 123-125.

Lawson, A.E., & Renner, J.W. (1974). A quantitative analysis of responses to Piagetian tasks and its implications for curriculum. Science Education, 58(4): 545-559.

Lawson, A.E., & Renner, J.W. (1975). Relationships of science subject matter and developmental levels of learning. Journal of Research in Science Teaching, 10(3): 1-12.

Leboutet-Barrell, L. (1976). Concepts of mechanics among young people. Physics Education, 11(7): 462-466.

Liebert, R.M., Poulos, R.W., & Marmor, G.T. (1977). Developmental psychology (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall, Inc.

Lin, H.S. (1979). Problem solving in introductory physics. Doctoral dissertation, Massachusetts Institute of Technology, Cambridge, MA.

Linden, M., & Wittrock, M.C. (1981). The teaching of reading comprehension according to the model of generative learning. Reading Research Quarterly, 17(1): 44-57.

Livermore, A.H. (1964). Science--A process approach. Science and Children, 1(8): 24-25.

Lochhead, J. (1979). An introduction to cognitive process instruction. In J. Lochhead & J. Clement (Eds.), Cognitive process instruction, Philadelphia, PA: The Franklin Institute Press.

Lochhead, J. (1978). Proceedings of the Third International Conference on Improving University Teaching. Baltimore, MD: University of Maryland.

Locke, J. (1894). An essay concerning human understanding [A.C. Fraser, Ed.]. Oxford: Clarendon Press. (Originally published 1690)

Lorenz, K. (1957). Companionship in bird life. In Schiller (Ed.), Instinctive behavior. New York: International University Press.

Lovell, K. (1971). In Green, Ford, & Flanner (Eds.), Measurement and Piaget. New York: McGraw Hill.

Ludlow, B.L., & Woodrum, D.T. (1982). Problem solving strategies of gifted and average learners on multiple discrimination task. Gifted Child Quarterly, 26(3).

McCloskey, M. (1979). Naive theories of motion (Award No. SED 7912741]. Research project supported by the Joint National Institute of Education, National Science Foundation Program of Research on Cognition Processes and the Structure of Knowledge in Science and Mathematics.

McCloskey, M. (1983). Intuitive physics. Scientific American, 248(4): 122-130.

McDermott, L.C. (1983). Critical review of research in the domain of mechanics. Proceedings of the First International Summer Workshop on Research in Physics Education, LaLande les Maures, France.

McDermott, L.C. (1984). An overview of research on conceptual understanding in mechanics. Manuscript submitted for publication to Physics Today.

Mayer, R.E. (1975). Information processing variables in learning to solve problems. Review of Educational Research, 45, 525-542.

Minstrell, J. (1982a). Conceptual development research in the natural setting of the classroom. In M. Rowe (Ed.), Education for the 80's: Science. Washington, DC: National Education Association.

Minstrell, J. (1982b). Explaining the "at rest" condition of an object. The Physics Teacher, 20, 10-14.

Minstrell, J. (1984). Teaching for the development of ideas. AETS Yearbook, vol. 11.

National Commission on Excellence in Education. (1983, April). A nation at risk: The imperative for educational reform. Washington, DC: U.S.G.P.O.

National Science Foundation Report. (1980). What are the needs of precollege science, mathematics and social science education? Views from the field. Directorate for Science Education, S.E. 80-9, U.S.G.P.O.

Nelson, P. (1985, January/February). Naturalness in theoretical physics. American Scientist, 73, 60-67.

Newton, L. (1946). Principia [Motte-Cajori, Eds.]. Berkeley, CA. (Original work published 1687)

Novak, J.D. (1977a). Epicycles and the homocentric earth: Or what is wrong with stages of cognitive development. Science Education, 61(3): 393-395.

Novak, J.D. (1977b). An alternative to Piagetian psychology for science and mathematics education. Science Education, 61(4): 453-477.

Novak, J.D. (1979). The reception learning paradigm. Journal of Research in Science Teaching, 16(6): 481-488.

Novak, J.D. (1981). Learning how to learn program. New York: Cornell University, Department of Education.

Nowicki, S., & Walker, C. (1974). The role of generalized and specific expectancies in determining academic achievement. Journal of Social Psychology, 94, 275-280.

Nussbaum, J. (1979). Children's conceptions of the earth as cosmic body: A cross age study. Science Education, 60(1): 83-93.

Nussbaum, J., & Novak, J. (1976). An assessment of children's concept of the earth utilizing structured interviews. Science Education, 60(4): 535-550.

Nussbaum, J., & Novick, S. (1980). Brainstorming in the classroom to invent a model: A case study. Jerusalem, Israel: The Hebrew University, Israel Science Center.

O'Brien, F. (1978). An error-free, quick, and enjoyed strategy for teaching multiple discriminations to severely delayed students. Mental Retardation, 16(4): 291-294.

Oden, M.H. (1968). The fulfillment of promise: 40 year follow-up of the Terman gifted group. Genetic Psychology Monographs, 77, 3-93.

Osborne, R.J. (1981). The framework: Towards action research. Learning in Science Project Working Paper No. 28. Hamilton, New Zealand: University of Waikato, Science Education Research Unit.

Osborne, R.J. (1984). Children's dynamics. The Physics Teacher, 22(8): 504-508.

Osborne, R.J., & Cosgrove, M.M. (1982). Students' conceptions of the changes of states of water. Journal of Research in Science Teaching.

Osborne, R.J., & Gilbert, J.K. (1980). A technique for exploring students' views of the world. Physics Education, 15(6): 376-379.

Osborne, R.J., & Wittrock, M.C. (1983). Learning science: A generative process. Science Education, 67(4): 489-507.

Ozman, H.A., & Craver, S.M. (1981). Philosophical foundations of education (2nd ed.). Columbus, OH: Charles E. Merrill Publishing Company.

Paris, S.G., & Lindauer, B.K. (1977). Constructive aspects of children's comprehension and memory. In R.V. Kail & J.W. Hagan (Eds.), Perspectives on the development of memory and cognition. Hillsdale, NJ: Lawrence Erlbaum Assoc.

Passow, S.H. (Ed.). (1979). The gifted and the talented: Their education and development. Chicago, IL: University of Chicago Press.

Pegnato, C.V., & Birch, J.W. (1959). Locating gifted children in junior high school. Exceptional Children, 25, 300-304.

Pennsylvania Department of Education. Guide for organizing and operating programs for the mentally gifted and talented. Harrisburg, PA: Bureau of Special Education, 1982.

Peters, P.C. (1982). Even honors students have conceptual difficulties with physics. American Journal of Physics, 50(6): 501-508.

Piaget, J. (1929). The child's conception of the world. New York: Harcourt, Brace & Co.

Piaget, J. (1930). The child's conception of physical causality. Totowa, NJ: Littlefield, Adams, and Company.

Piaget, J. (1954). Construction of reality in the child. New York: Basic Books, Inc.

Piaget, J. (1964). Development and learning. Journal of in Science Teaching, 2(3): 76-186.

Piaget, J. (1965). The moral judgement of the child. New York: Free Press.

Piaget, J. (1969). The intellectual development of the adolescent. In G. Caplan & S. Lebovici (Eds.), Adolescence: Psychosocial perspectives. New York: McGraw-Hill.

Piaget, J. (1970). The child's conception of movement and speed. London: Routledge & Kegan Paul.

Piaget, J. (1971). The theory of stages in cognitive development. In D.R. Green (Ed.), Measurement and Piaget. New York: McGraw-Hill.

Piaget, J. (1972). Judgment and reasoning in the child. Totowa, NJ: Littlefield, Adams, and Company.

Piaget, J. (1974). Understanding causality. New York: Norton.

Pope, A. (1903). Collected works. Boston: Houghton Mifflin. (Original work published 1698)

Pope, M.L. (1980). Practical considerations in the use of the repertory grid techniques. United Kingdom: University of Surrey [I.E.T. Mimeograph]

Pope, M., & Gilbert, J. (1983). Personal experience and the construction of knowledge in science. Science Education, 67(2): 193-203.

Poincaré, H. (1929). Science & method. New York: Dover Publication.

Physical Science Study Committee (P.S.S.C.). (1960). *Physics*. Boston, MA: D.C. Heath and Company.

Quattrone, J.J., & Courville, G.E. (1977). Flexibly structured, inquiry-based, physical science course for education students. *American Journal of Physics*, *45*(2): 154-157.

Reese, H.W. (1976). Models of memory development. *Human Development*, *19*, 201-303.

Reisen, A.H. (1958). Plasticity of behavior: Psychological aspects. In H.F. Harlow & C.H. Woolsey (Eds.), *Biological and behavioral bases for behavior* (pp. 425-450). Madison, WI: University of Wisconsin Press.

Renner, J.W. (1976). Significant physics content and intellectual development--Cognitive development as a result of interacting with physics content. *American Journal of Physics*, *44*(3): 218-222.

Renner, J.W. (1978). *Research, teaching, and learning with the Piaget model*. Norman, OK: University of Oklahoma Press.

Renner, J.W., Grant, R.M., & Sutherland, J. (1978). Content and concrete thought. *Science Education*, *62*, 215-221.

Renner, J.W., & Lawson, A.E. (1973). Promoting intellectual development through science teaching. *Physics Teacher*, 273-276.

Renner, J.W., & Stafford, D.G. (1972). *Teaching science in the secondary schools*. New York: Harper & Row.

Resnick, L.B. (1983). Mathematics and science learning: A new conception. *Science*, *220*, 447.

Resnick, L.B., & Glaser, R. (1976). Problem-solving and intelligence. In L.B. Resnick (Ed.), *The nature of intelligence*. Hillsdale, NJ: Erlbaum.

Renzulli, J.S. (1978). What makes giftedness? *Phi Delta Kappan*, *60*, 180-184.

Renzulli, J. (1982). What makes a problem real? Stalking the illusive meaning of qualitative differences in gifted education. *Gifted Child Quarterly*, *26*, 147-156.

Riegal, K.F. (1973). Dialectic operations: The final period of cognitive development. *Human Development*, *16*, 346-370.

Ring, D.G., & Novak, J.D. (1971). The effect of cognitive structure variables on achievement in college chemistry. *Journal of Research in Science Teaching*, *8*(4): 325-333.

Rumelhart, D.E., & Ortony, A. (1977). The representation of knowledge in memory. In R.C. Anderson, R.J. Spiro, & W.J. Montague (Eds.), *Schooling and the acquisition of knowledge*. Hillsdale, NJ: Erlbaum.

Russell, B. (1945). *A history of western philosophy*. New York: Simon and Schuster.

Sagan, C. (1980). *Cosmos*. New York: Random House.

Sagan, C. (1982). Address presented to a national convocation of the National Academies of Science and Engineering. Washington, DC.

Saxon, D.S. (1982). Liberal education in a technological age. *Science*, *218*, 4575.

Schlessinger, F. (1973). *Survey of science teaching in public schools of the United States* (1971). *Secondary Schools*. Columbus, OH: Center for Science and Mathematics Education in Cooperation with ERIC/Science.

Schrodinger, E. (1935). *Science, theory, and man*. New York: Dover, Inc.

Science Curriculum Improvement Study (SCIS). (1968). Chicago: Rand McNally.

Science Curriculum Improvement Study (SCIS). *Materials*. (1980). Chicago: Rand McNally.

Science and Engineering: Education for the 1980's and Beyond. (1980, October). Prepared by National Foundation and the Department of Education. Washington, DC: U.S. Government Printing Office.

Selman, R. (1980). *The growth of interpersonal understanding development and clinical analysis*. New York: Academic Press.

Selman, R.L., Krupa, M.P., Stone, C.R., & Jaquette, D.S. (1982). Concrete operational thought and the emergence of the concept of unseen force in children's theories of electromagnetism and gravity. Science Education, 66(2): 181-194.

Shavelson, R.J. (1974). Methods for examining representations of a subject-matter structure in a student's memory. Journal of Research in Science Teaching, 11(3): 231-249.

Shayer, M., & Adey, P. (1983). Towards a science of science teaching. London: Heinemann Educational Books.

Shymansky, J. (1982). Preliminary results cited in testimony presented by S. Klein, President of the National Science Teachers Association (1982) to the U.S. Senate Sub-committee on N.S.F. funding. [Project NSF SED 80-12310]

Sills, T.W. (1977, February 7). Assessment of Piagetian formal operation reasoning and its relationship to physics classroom achievement. Presented at the Meeting of the AAPT, Chicago, IL.

Sjoberg, S., & Lie, S. (1981). Ideas about force and movement among Norwegian pupils and students [Technical Report No. 81-11]. Oslo, Norway: University of Oslo.

Skinner, B.F. (1953). Science and human behavior. New York: Free Press.

Slobin, D.I. (1971). Psycholinguistics. Glenview, IL: Scott & Foresman.

Smith, H.A. (1963). Educational research related to science instruction for the elementary and junior high school--A review and commentary. Journal of Research in Science Teaching, 1(3): 199-225.

Smith, H.A. (1969). Curriculum development and instructional materials. Review of Educational Research, 39(4): 397-413.

Snow, C.P. (1960). The two cultures and the scientific revolution. New York: Cambridge University Press.

Spence, K.W. (1951). Theoretical interpretations of learning. In S.S. Stevens (Ed.), Handbook of experimental psychology (pp. 690-729). New York: Wiley.

Stake, R.E., & Easley, J. (1978). Case studies in science education (2 vols.). Washington, DC: U.S. Government Printing Office.

Stanley, J.C. (1979). The study and facilitation of talent for mathematics. In A.H. Passow (Ed.), The gifted and the talented: Their education and development. Chicago, IL: University of Chicago Press.

Stanley, J.C., George, W.C., & Solano, C.W. (1977). The gifted and the creative: A fifty-year perspective. Baltimore, MD: Johns Hopkins University Press.

Stead, B., & Osborne, R.J. (1980). Exploring science student's concept of light. Australian Science Teacher's Journal, 26(3): 84.

Sternberg, R.J. (1981). Intelligence and non-entrenchment. Journal of Educational Psychology, 73, 1-16.

Sternberg, R.J. (1982). Lies we live by: Misapplication of tests in identifying the gifted. Gifted Child Quarterly, 26(4): 157-161.

Sternberg, R.J. (1983). Components of human intelligence. Cognition, 15, 1-48.

Sternberg, R.J., & Rifkin, B. (1979). The development of analogical reasoning processes. Journal of Experimental Child Psychology, 27, 195-232.

Strauss, S. (1981). Cognitive development in school and out. Cognition, 30, 295-300.

Taylor, L.W. (1941). Physics, The pioneer science (vol. 1). New York: Dover Publications, Inc.

Teleford, C.W., & Sawrey, J.M. (1981). The exceptional individual (4th ed.). Englewood Cliffs, NJ: Prentice-Hall.

Terman, L.M. (1904). A preliminary study in the psychology and pedagogy of leadership. Pedagogical Seminary, 11, 413-451.

Terman, L.M. (1906). Genius and studipity. Pedagogical Seminary, 13, 307-373.

Terman, L.M. (1925). Mental and physical traits of a thousand gifted children. In L.M. Terman (ed.), Genetic Studies of Genius. Stanford, CA: Stanford University Press.

Terman, L.M., & Oden, M.H. (1947). The gifted child grows up. Stanford, CA: Stanford University Press.

Terman, L.M., & Oden, M.H. (1959). The gifted group at mid-life. Stanford, CA: Stanford University Press.

Thompson, W.R., & Heron, W. (1954). The effect of restructuring early experience on the problem-solving capacity of dogs. Canadian Journal of Psychology, 8, 17-31.

Thornburg, H.D. (1984). Introduction to educational psychology. New York: West Publishing Company.

Thorndike, E.L. (1971). The fundamentals of learning. New York: AMS Publications. (Original work published 1932)

Torrence, E.P. (1959). Explorations in creative thinking in the early school years: A progress report. In Taylor (Ed.), The Third University of Utah Research Conference on the Identification of Creative Scientific Talent. Salt Lake City: Univeristy of Utah Press.

Torrance, E.P. (Ed.) (1960). Talent and education. Minneapolis, MN: University of Minnesota Press.

Torrance, E.P. (1973). Non-test indicators of creative talent among disadvantaged children. Gifted Child Quarterly, 17, 3-9.

Trojcak, D.A. (1979). Science with children. New York: McGraw-Hill Book Co.

Trowbridge, D.E., & McDermott, L.C. (1981). Investigation of student understanding of the concept of acceleration in one dimensions. American Journal of Physics, 49(3): 242-253.

Tuddenham, R.D. (1966). Jean Piaget and the world of the child. American Psychologist, 21, 207-217.

Upton, G. (1978). *The analysis of cross-tabulated data*. New York: John Wiley & Sons.

Viennot, L. (1979). Spontaneous reasoning in elementary dynamics. *European Journal of Science Education*, *11*, 205-221.

Wadsworth, B.J. (1978). *Piaget for the classroom teacher*. New York: Longman, Inc.

Wales, C.E., & Stager, R.A. (1978). *The guided design approach*. Englewood Cliffs, NJ: Educational Technology Publications.

Walters, L., & Sieben, G. (1974). Cognitive style and learning science in elementary schools. *Science Education*, *58*(1): 65-74.

Ward, L.F. (1906). *Applied sociology*. Boston: Ginn.

Watson, J.B., & Rayner, R. (1920). Conditioned emotional reactions. *Journal of Experimental Psychology*, *3*, 1-14.

Watts, D.M. (1983). A study of school children's alternative frameworks of the concept of force. *European Journal of Science Education*, *5*, 217.

Weil, M., & Joyce, B. (1978). *Information processing model of teaching*. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Weiss, I.R. (1977). *Report of the 1977 national survey of science, mathematics and social studies education*. Washington, DC: U.S. Government Printing Office, National Science Foundation.

Weisskopf, V.F. (1976, June). Is physics human? *Physics Today*.

Weisskopf, V.F. (1979, Autumn). Art and science. *American Scholar*, *48*(4).

Weisskopf, V. (1983, September). Lecture presented on WVIA Public Broadcasting Syste,, Inc. NOVA Series.

Weisz, J.R., & Zigler, E. (1979). Cognitive development in retarded and nonretarded persons: Piagetian tests of the similar sequence hypothesis. *Psychological Bulletin*, *86*, 831-851.

Welch, W.W. (1977, March). The needs of science education as perceived by principals and teachers. Paper presented at the Association for the Education of Teachers in Science, annual meeting. Cincinnati, OH.

Welch, W.W. (1979). Evaluating the impact of national curriculum projects. Science Education, 60(4): 475-483.

Wertheimer, M. (1938). Laws of organizations in perceptual forms. In W.D. Ellis (Ed.), A source book of gestalt psychology (pp. 71-88). New York: Harcourt, Brace & World. (Original work published 1923)

Whimby, A. (1979). Teaching analytical reasoning in mathematics. In J. Lochhead & J. Clement (Eds.), Cognitive process instruction. Philadelphia, PA: The Franklin Press.

White, B. (1984). Designing computer games to help physics students understand Newton's laws of motion. Cognition and Instruction, 1, 69.

Whitehead, A.N. (1968). Science and the modern world. New York: Macmillan.

Whitehead, A.N., & Russell, B. (1968). Principia mathematica. Cambridge, England: University Press.

Wittrock, M.C. (1977). Learning as a generative process. In M.C. Wittrock (ED.), Learning and instruction. Berkeley, CA: McCutcheon.

Wittrock, M.C. (1978). Developmental process in learning from instruction. Journal of Genetic Psychology, 132, 37-54.

Wolfinger, D.M. (1982). The effect of science teaching on the young child's concept of Piagetian physical causality: Animism and dynamism. Journal of Research in Science Teaching, 19, 7.

Yukawa, H. (1973). Creativity and intuition. Tokyo: Kodansha International. [Distributed in the U.S. by Harper & Row, New York]

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